Faculty of Engineering and Science
Department of Electrical and Computer Engineering

Evaluating Byzantine-Based Blockchain Consensus Algorithms for Sarawak's Digitalized Pepper Value Chain

Kueh Reng Yi

0000-0003-0848-8699

**This thesis is presented for the Degree of
Master of Philosophy
of
Curtin University**

MAY 2022

Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Human Ethics (For projects involving human participants/tissue, etc) The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number #HRE2020-0413

Signature: ……………………………………………………………………

Date: ………………………………………

Thesis Committee

Thesis Chair: A/Prof. Dr. Lenin Gopal

Principal Supervisor: A/Prof. Dr. Ling Huo Chong

Co-Supervisors: A/Prof. Dr. Tang Fu Ee,

Dr. Tan Yee Yong,

Ms. Carrie Ho Lee Ing

ACKNOWLEDGEMENT

First and foremost, I would like to express my utmost gratitude to all of my supervisors: A/Prof. Dr. Ling Huo Chong, A/Prof. Dr. Tang Fu Ee, Dr. Tan Yee Yong, and Ms. Carrie Ho Lee Ing for their absolute wisdom and patience towards my research. Secondly, I am grateful for having the opportunity to partake this course, which was formerly recommended by Dr. Raymond Choo Wee Chiong, and also to my parents that brought me to Curtin University in the first place. Lastly, though it may not be reached, I would like to extend my appreciation to all of the pepper stakeholders that were recruited for participating the qualitative interview. Without their participation, this thesis will be completely ruled out due to the deficiency of data pertaining to Sarawak's pepper value chain.

ABSTRACT

Known as the "King of Spice", pepper (*Piper nigrum*) is the most widely used and traded agricultural product in the world. In Sarawak, pepper is listed as the few industrial crops in producing and contributing the most to the gross domestic product (GDP) of the country, Malaysia. Today, there are 67,000 pepper farmers, a majority of whom are smallholder farmers from the rural communities located in Sarawak. However, the recent price fluctuation in the global pepper market has caused some farmers to abandon pepper farms due to the lower pepper prices against the high cost of input materials and farm maintenance. Also, pepper farmers are limited in their marketing choices and bargaining power when dealing with buyers due to their geographic remoteness, small production quantity, and variable product. These result in smallholder farmers having difficulties to enter the high-value markets. Therefore, in order to improve the participation of smallholder farmers in the pepper value chain in particularly entry into high-value markets, Sarawak's pepper value chain is studied to understand the linkages and pain points of pepper stakeholders. To carry out the study on Sarawak's pepper value chain, a snowballing technique is implemented to acquire subsequent stakeholders when conducting interviews among stakeholders, thus attaining the complete structure of Sarawak's pepper value chain. Additionally, blockchain technology with Practical Byzantine Fault Tolerance (PBFT), a Byzantine-based consensus algorithm, is proposed to minimize some of the identified pain points faced by the pepper stakeholders. Byzantine-based consensus algorithms are used to achieve the same agreement on a single data value, including transactions and block state, and to maintain system continuity even when several nodes have failed to respond or give false and inconsistent messages on the distributed network. With the PBFT consensus algorithm on-board, the blockchain network (BCN) will operate without miners as it relies on the message-transfer mechanism to achieve the total consensus. Besides, the PBFT consensus algorithm with varying network structures were evaluated and a blockchain system architecture for the Sarawak pepper value chain were devised. Upon comparison between network structures, the group network structure dominated the entirety of the experiment and presented as the proposed network structure, with the addition of specific nodes such as relay, storage, administer and also brackets: bench and penalty to facilitate and maintain the longevity of the BCN. Together with the discovered Sarawak's pepper value chain and the chosen PBFT network structure, a digitalized Sarawak's pepper value chain framework is created by integrating with the blockchain system architecture and its consensus algorithm.

Keywords: *blockchain, Byzantine, consensus algorithms, digitalized, pepper, Sarawak, stakeholders, value chain*

Contents

List of Figures

List of Tables

List of Acronyms

AES	Advanced Encryption Standard
ARC	Agriculture Research Centre
BCN	Blockchain Network
BFT	Byzantine Fault Tolerance
CLI	Command Line Interface
CMD	Command Prompt
dApp	Decentralized Application
DDoS	Distributed Denial-of-Service
DLT	Distributed Ledger Technology
DoAS	Department of Agriculture Sarawak
DoSM	Department of Statistics Malaysia
DSA	Digital Signature Algorithm
GAP	Good Agricultural Practices
GDP	Gross Domestic Product
GI	Geographical Identification
GMP	Good Manufacturing Practices
GSM	Global System for Mobile Communication
IPC	International Pepper Community
KPMG	Klynveld Peat Marwick Goerdeler International Cooperative
MD5	Message Digest 5
MIT	Massachusetts Institute of Technology
MoU	Memorandum of Understanding

MPB	Malaysian Pepper Board
NFC	Near-Field Communication
NPK	Nitrogen-Phosphorus-Potassium
PBFT	Practical Byzantine Fault Tolerance
PKCS	Public Key Cryptography Standards
PMB	Pepper Marketing Board
PSR	Performance, Scalability, and Reliability
PoA	Proof of Authority
PoS	Proof of Stake
PoW	Proof of Work
P2P	Peer-to-Peer
QCL	Quality Control Laboratories
RFID	Radio-Frequency Identification
RSA	Rivest-Shamir-Adleman
SCM	Supply Chain Management
SDEC	Sarawak Digital Economy Corporation
SDMA	Scalable Dynamic Multi-Agent
SHA	Secure Hash Algorithm
SPEA	Sarawak’s Pepper Exporter Association
TPS	Transactions Per Second
T-PBFT	EigenTrust-Based Practical Byzantine Fault Tolerance
UID	Unique Identification
UMTS	Universal Mobile Telecommunications System
UPM	University Putra Malaysia

CHAPTER 1: INTRODUCTION

This chapter comprises of the project overview and motivation in researching Sarawak's pepper value chain along with the improvements on the constraints with blockchain technology, which is empowered by a robust PBFT consensus algorithm. Here, pain points are defined as constraints encountered by pepper stakeholders in their daily operation. The research is divided into 3 stages: the determination of the Sarawak pepper value chain and its pain points, the benchmark of chosen PBFT network structures, and the integration on both aspects into a projection of blockchain system architecture.

1.1 Background of the Study

The pepper industry is considered as one of the main contributors to Malaysia's economy, as it is one of the most important and resilient crops of the Malaysian agriculture sector. As demonstrated from the GDP 2017 report, the agriculture sector had contributed 8.2% or RM 96.0 billion to the nation's GDP and pepper is considered as a major contributor for this economic activity [1]. Oil palm and rubber contributed 46.6% and 7.3% respectively to the agriculture sector while other commodities such as pepper, cocoa, and paddy contributed 18.6% [1]. According to the Malaysian Pepper Board (MPB), the total production of pepper in Malaysia was 30,433 Mt (metric tons), with 11,640 Mt (metric tons) exported to international markets, and the export earning was RM 308.87mil in 2017 [2]. As a result, Malaysia is ranked as the fifth largest pepper-producer in the world. The Malaysian state of Sarawak contributes a total of 95% of the pepper production in Malaysia, and the remaining 5% are from Sabah and Johor [3]. In 2019, it was reported that the country had produced 34,294 Mt (metric tons) of pepper and contributed RM1.95 billion to the nation's gross domestic product (GDP), which is around 0.1 percent of Malaysia's commodities GDP [4]. With that, it is noteworthy to understand how the pepper industry can manage to contribute the total gross amount to the nation by delving into its structural flow, the prominent roles situated inside the current pepper value chain, and any improvements to channeling the product flow with newly value-adding activities such as the usage of business technologies and the implementation of the latest smart devices available in the commercial market.

1.2 Problem Statements

While the pepper crop can provide a major contribution to the nation's and state's agricultural economy, the recent drop in the price of pepper has affected the livelihood of pepper farmers drastically, resulting in many of them having to abandon pepper farming due to the high cost of maintenance, fertilizers and pesticide [5]. Furthermore, pepper farmers have little bargaining power in selling their commodity, as they have limited access to marketing channels [5]. An inherent issue in Sarawak's pepper industry is the lack of clear linkages between the pepper value chain stakeholders. This prevents smallholder farmers from accessing or participating the pepper value chain. Hence, a technological medium such as a blockchain platform could provide an intervention and address some of the concerns that are limiting the participation of smallholder farmers in the pepper value chain. Platforms that utilize blockchain technology can provide total provenance and report the status of harvested crops laid within the agricultural value chain. The underlying function can create clear linkages between the pepper value chain stakeholders and track the flow of the pepper products.

In addition, the study of blockchain is important because of the utilization of distributed ledger technology (DLT), whereby online transactions are shared between system nodes for data immutability and the high-degree of security that can be provided by its underlying consensus algorithms. The consensus mechanism for the proposed blockchain architecture to digitalize Sarawak's pepper value chain will be encircled around Byzantine-based consensus algorithms due to several factors such as the fault-tolerant nature that helps to enhance the availability and reliability using state machine replicated services [6], high transactions per second (TPS) performance, minimum hardware requirements, and scalable permissioned networks. Thus, the study on Byzantine-based consensus algorithms is relatively important for the researchers to understand the theoretical algorithms proposed in recent papers [6], [7] - [9], and evaluate their strengths and weaknesses for a secure blockchain architecture integrated into Sarawak's pepper value chain framework accordingly.

1.3 Research Objectives

The objectives of this research are:

- To identify Sarawak's pepper value chain by determining stakeholders' linkages and pain points.
- To evaluate variants of network structures revolving around the PBFT algorithm.
- To study the underlying architecture of blockchain technology and develop a digitalized Sarawak's pepper value chain framework with the proposed blockchain system architecture and its consensus algorithm.
- To verify the proposed value chain and its consensus algorithm.

1.4 Contributions from the Research

This research produces two major contributions:

1. An exploratory research on linkages and pain points of Sarawak's pepper stakeholders was conducted by utilizing snowball sampling as the method of data collection. As a result, the collective information is beneficial to construct a complete Sarawak's pepper value chain, which is absent from any related literatures encountered thus far.

2. PBFT-derived consensus algorithms were reviewed and evaluated based on the metrics of performance, scalability, and reliability. The network structures evaluated are distinct, namely the basic, group, and layer. The comparison between the three network structures was made to observe the minimum time required for each network structure to consent the

request transaction, with the chosen network structure being integrated into the proposed blockchain system architecture for digitalizing Sarawak's pepper value chain.

1.5 Significance of the Study

The proposed research study will be able to provide some major contributions to the following sectors:

i) The Sarawak Government

At the end of the study, a value chain regarding to Sarawak's pepper sector will be delivered along with the pain points and linkages. Besides, any competitive advantages that may benefit the domestic pepper sector will also be described upon researching foreign pepper value chains, including the usage of blockchain technology as the value addition to the chain into the recommendation chapter. This potential of blockchain technology to the pepper value chain will encourage the state government and pepper statutory body, the MPB to embrace its benefits and forthcoming into the pepper industry.

ii) The Application and Architecture Practitioners

As a technologist, it is crucial to understand the application and physical layers of an underlying technology. For that reason alone, blockchain practitioners will require to learn the system architecture and how the operation circulates within the layered system and the running network. Intrinsically, the operation comprises of the procedures of digital transactions, consensus agreements between nodes, concatenation of verified transactions into blocks, and ledger distribution to network nodes to prevent alteration of verified data by malicious users. All information will be provided comprehensively along with the integration map between the blockchain architecture and Sarawak's pepper value chain.

1.6 Thesis Outline

This thesis presents the research on Sarawak's pepper value chain and digitalization towards the particular industry with the help of evaluated consensus algorithm, which is the core mechanism of blockchain technology. The chapters are detailed as follows:

Chapter 2: Literature Review

Prior to the qualitative interview, established pepper value chains are studied to estimate the structure of Sarawak's pepper value chain; the characteristics, linkages and pain points occurred amongst pepper stakeholders. In addition, blockchain technology and its consensus algorithm are also being reviewed to define its purpose and how it can revolutionize the agricultural industry.

Chapter 3: Research Methodology

Research methods to acquire data and conduct qualitative interviews are described in this chapter. Besides, a research framework is drawn to show the development phases and its cycle towards the end goal.

Chapter 4: Results and Discussions on Qualitative Interview

After collecting sufficient data from each stakeholder category, the results are sought for similar themes and compiled into tables and visualized charts to compare the significance of each pain points based on the total weightage, in conjunction with the comparison of the relevancy of local results to the case studies of foreign pepper industry from the literature review.

Chapter 5: Evaluation and Implementation of Network Structures in PBFT Consensus Algorithm

An experiment is conducted to evaluate the variants of network structure for the PBFT consensus algorithm. During the node simulation, results are logged into their respective data files and compared based on the performance, scalability, and reliability metrics. Subsequently, a refined network structure is also proposed along with additional mechanisms to regulate message traffics and counter faults among the network nodes. In addition, a blockchain system architecture and the digitalization of Sarawak's pepper value chain are conceptualized as an early preview of real-life implementation.

Chapter 6: Conclusions and Future Work

As a full closure, an overall summary is provided by stating the achieved objectives, starting from identifying Sarawak's pepper value chain, then evaluating network structures for the PBFT consensus algorithm, and finally integrating both results into building a blockchain system architecture along with the digitalization of Sarawak's pepper value chain. By succeeding the above objectives, the proposed value chain and consensus algorithm are considered as verified and able to take the recommended steps for the actual implementation.

CHAPTER 2: LITERATURE REVIEW

This chapter presents a review of the past research work in relevance to the present study objective. It is also presented to synthesize the gathered information such as theoretical perspective and empirical shreds of evidence from various sources into a summary.

2.1 Porter's Value Chain

The concept of the value chain was presented by Michael Porter in 1980 and explained thoroughly in his book, named "*Competitive Advantage: Creating and Sustaining Superior Performance*" [10]. Currently, it is recognized as the standardized value chain framework that helps to extract specifics by dividing a full-fledged business into several activities. By doing so, a firm with the business can locate the source of competitive advantages and make various improvements such as lowering operating costs of specific activities located in the processing phase and maximize value creation concurrently [11]. Apart from that, Porter also distinguished the value chain activities into two variants: the primary and support activities. Primary activities such as production, collection, processing, wholesaling, and retailing are handled by stakeholders or actors of the value chain whereas support activities are institutions and extension services that contributed indirectly to the end product or service [11].

The value chain is a publicized framework that describes a set of businesses, activities, and stakeholders involved in fulfilling a finished product or service to customers, either domestically or internationally [12]. It is also known as a 'group of vertically linked economic agents' that generate values for the end consumer [13], and also the horizontal bonds between stakeholders that serve the same function in the value chain [14]. Products are infrequently used in raw forms which require to undergo several processing activities provided in treatment plants, then packaged and marketed until it finally arrives at buyers' doorstep [15].

2.2 Agricultural Value Chain

To date, the Porter's Value Chain Framework has been utilized in various business sectors, including in agriculture, where it is often referred as the agricultural value chain. By definition, an agricultural value chain is a set of actors and activities that consecutively adds values to each subsequent stage from a basic agricultural product to the end consumers. The value chain can form vertical linkages between stakeholders at different stages of the value chain to move product or service to the end market and horizontal linkages between stakeholders which partake a similar role to jointly accomplish common goals such as the farmer associations [16].

There are three significant levels of the agricultural value chain that can be observed. Firstly, the inner layer or micro-level has value chain actors that contribute efforts directly to the product. Secondly, the middle layer or meso-level has the value chain supporters which provide extension and financial services to the micro players although they are not directly participate in any activities operated by the stakeholders. Lastly, the outer layer or macro level has value chain influencers, including statutory and regulatory bodies who build public infrastructures and construct policies as a framework that needs to be followed by the micro and meso players when engaging either in business-related or production-related operations [17]. Others have stated that there is one additional level that explains the value chain concept, the meta-level which is the socio-cultural factor. For instance, the facilitation of business linkages, business attitudes, and the trust relationship among the value chain actors [18].

Unsurprisingly, smallholder farmers or producers are frequently situated in the disadvantageous position within an agricultural value chain. One of the main reasons is that smallholder farmers do not have any sufficient and reliable market information about their own harvested crops [19]. Furthermore, the lack of quality assurance in their products also causes traders to offer lower prices as they do not know what quality to expect and reduce the uncertainty of bad crops. For instance, a farmer produces mandarins but does not separate the healthy and large from the small and spotty mandarins. The buyers may pose skepticism and offer the lowest price they could offer [20].

Hence, a definite solution to these problems is to form a farmer union that helps individual farmers to gain networks or relationships with different links in the agricultural value chain and have access to various farm support services [20]. Farmer organizations will benefit individual farmers in reducing transaction costs in input and output markets, drastic improvements onto the product assembly and quality assurance, and the accessibility of inputs, credits, and technical assistance [19]. Additionally, farmer organizations will have the capability of negotiating contract terms and conditions for participated small-scale farmers [21].

2.2.1 Characteristics of the Agricultural Value Chain

In developing countries, agriculture can be characterized into parallel dual-channel value chains for an equal amount of the final product, where one is a traditional or informal chain and the other modern or formal chain [22]. Smallholder farmers are often at a disadvantage, as they most likely participate in the informal chain, which is the delivery of products to village collectors or local middlemen, and then straight to small local stores. On the other hand, formal chains are mostly utilized by large farms, estates or joint associations of smallholder farmers to improve commercialization by exporting packaged goods to international markets [20]. With highly competitive selling groups aiming at high-value markets, smallholder farmers face difficulties in participating in the formal chain and are often characterized as low-quality agricultural and food sources [22].

According to a published report "*The agricultural and food value chain*" from Klynveld Peat Marwick Goerdeler International Cooperative (KPMG), agricultural value chains are far more volatile and complex compared to a typical value chain. The agribusiness environment is gradually becoming more volatile due to several factors that have arisen in recent years: the changing climate, political actions, and social changes [23]. The fluctuating crop yields and supply shortfalls are the outcomes propelled by the drastic weather changes. Regarding the past events, supply is considerably quite erratic whereas demand is relatively stable throughout the years or even decades. Besides, the advent of global warming is driving more volatility as average temperatures and rainfalls are inevitably increased [23].

On the political front, government actions may result in volatility in agribusiness as well. For example, palm oil has always been a political and industrial crop with concerns of its provenance and sustainability [24]. This vegetable oil has led to huge deforestation, biodiversity loss, and massive forest fires. The European Commission has even concluded palm oils to be phased out from transport fuels and caused trading tensions between top producing-countries such as Malaysia and Indonesia [24]. Besides, there are also social tensions where consumers are raising campaigns against unsustainable oil palm production, resulting in many palm oil brands to comply by sourcing from sustainable harvests and label with certified RSPO stickers [25]. Hence, the political action and social changes are considered the manipulating variables that may influence the volatility on commercial trades of world markets.

2.3 Global Pepper Industry

In 2018, the total global pepper production was approximately 532kMt (kilometric tons), which consisted of 420kMt of black pepper, and 112kMt of white pepper. According to the Pepper Statistical Yearbook, 2018 presented by International Pepper Community (IPC), Vietnam (38.5%) takes the crown as the largest producer and exporter of pepper with a whopping 205kMt of pepper production and exported 235kMt of pepper valued at USD 774 mil. The staggering amount of pepper production and exports indicates that Vietnam is the country with the largest contribution to the pepper market. Following the trail are Brazil (13.5%), Indonesia (13.1%), India (12%), China (6.6%), Malaysia (5.8%), Cambodia (3.9%), Sri Lanka (3.8%), and others whose production is less than 10kMt [26].

Table 2.1: Total Production of Pepper by Country, 2009-2018 in Mt (metric tons) [26, Tab. 1.04]

COUNTRY	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Brazil	40,700	34,000	35,000	32,000	34,000	39,000	44,000	41,600	65,000	72,000
India	50,000	50,000	48,000	43,000	65,000	37,000	70,000	48,500	57,000	64,000
Indonesia	50,000	59,000	47,000	75,000	63,500	52,000	80,000	77,000	75,000	70,000
Malaysia	22,000	23,5000	25,000	23,000	19,000	20,500	22,500	23,000	23,500	31,073
Sri Lanka	15,767	17,332	10,834	18,604	28,000	14,139	28,177	18,485	29,545	20,135
Vietnam	123,750	110,000	120,000	118,000	122,000	148,760	122,000	170,000	200,000	205,000
China, PR	29,000	32,000	32,300	28,000	28,000	28,000	29,000	29,000	26,000	35,000
Thailand	6,730	6,391	4,395	4,000	6,000	6,000	5,500	5,000	5,000	5,000
Madagascar	5,010	5,018	4,092	4,000	4,000	4,000	4,000	3,500	4,000	4,000
Cambodia	1,000	1,300	1,500	5,400	6,000	7,500	9,800	11,800	20,000	20,551
Ecuador & Others	2,750	3,000	3,250	3,500	3,800	2,500	2,200	3,700	5,000	6,000
TOTAL	**346,707**	**341,541**	**331,371**	**354,504**	**379,300**	**359,399**	**417,177**	**431,585**	**510,045**	**532,759**

Table 2.2: Total Export of Pepper by Country, 2009-2018 in Mt (metric tons) [26, Tab. 1.07]

COUNTRY	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Brazil	35,770	30,761	32,695	29,129	30,605	34,169	38,034	31,100	59,500	72,580
India	21,267	18,487	24,464	18,402	20,137	20,400	28,520	23,850	18,250	16,724
Indonesia	50,642	62,599	36,487	62,608	47,908	34,732	58,075	53,100	42,687	47,613
Malaysia	13,124	14,077	14,201	10,588	12,105	13,429	13,624	12,116	12,184	11,779
Sri Lanka	6,576	12,225	5,057	10,488	21,328	8,031	16,660	7,875	13,313	13,118
Vietnam	134,405	116,872	123,861	116,842	132,764	156,396	133,650	179,233	215,000	235,889
China, PR	2,083	4,569	4,447	2,563	1,606	1,042	1,707	1,425	1,300	2,522
Thailand	2,489	600	518	238	224	251	291	322	278	418
Madagascar	1,606	1,844	1,784	1,373	1,781	2,105	1,931	2,026	1,983	3,314
Cambodia	6,700	5,000	7,200	7,800	6,900	7,400	8,600	10,500	16,800	18,000
Ecuador & Others	800	2,000	750	700	745	1,100	1,400	2,400	4,200	4,434
TOTAL	**275,462**	**269,033**	**251,464**	**260,730**	**276,103**	**279,055**	**302,492**	**323,947**	**385,495**	**426,391**

2.4 Case Studies: Foreign Pepper Value Chains

Pepper is a staple condiment in culinary, and considered the highest consumption spice compared to others. With the conducive environment available in Malaysia, especially Sarawak, this particular crop has been the cash crop for decades, which contributes well to the nation's agriculture Gross Domestic Product (GDP) [27], [28]. Despite the importance, there are currently no papers or studies that focuses on its value chain, thereby giving the opportunity to study Sarawak's pepper value chain, starting by reviewing to relevant research papers that described foreign pepper value chains. The motivation was to understand the fundamental structure of the pepper value chain and a mild comparison to Sarawak's pepper value chain afterwards.

2.4.1 Dak Lak, Vietnam [29]

Smallholder farmers have been producing 95% of total pepper production in Dak Lak. In most cases, the pepper berries are sold within two to three months as they have not enough storage to accommodate the harvested pepper berries. There are currently no public infrastructures such as warehouses to have farmers to share and deposit the crops. Moreover, the immediate cash for survival leads to a factor for them to sell off harvested pepper crops as well. For those who can stock pepper in their household are considered within the line of rich and middle-income families and have extra earnings from other agricultural and non-agricultural activities. On the other hand, there are also large producers including private farms and state companies that contribute 5% of the total pepper production in the province. Farms are equipped with storing facilities for creating pepper stockpiles during unfavorable market pricing. When the market price has reverted to normal or higher than expected, stockpiles will be immediately sold off to gain the profit margin.

Collectors normally traveled to segregated pepper farms for purchasing the harvested pepper berries from smallholder farmers or private companies with highly facilitated farms. The pepper berries obtained are taken to large collectors or traders in the value chain. At the same time, large collectors will also purchase from the smallholder farmers if available and sell the collected berries to traders which will be cleaned and graded according to standard from the subsequent buyer. In general, the transaction of the pepper berries between the farmers and the collectors have amounted approximately within 10kg to 1Mt. In Dak Lak, traders are tasked to undergo the activities of cleaning and grading the received pepper berries according to requirements specifically mentioned by the requested buyers. However, some traders did not refer to the market price negotiated with the collectors instead which cause unfairness among sellers that were offered higher prices compared to others. After the first processing phase, traders will sell the half-processed pepper berries to the wholesalers located in Buon Ma Thuot and export companies in Ho Chi Minh city.

Wholesaling agents in Dak Lak usually have their own storing facilities with a capacity of around 10-15Mt of storing half-processed pepper. However, most of the wholesalers do not store it in full capacity due to uncertainty like fluctuations in the pepper market. In conjunction with huge storing facilities, wholesalers have contracted with transportation companies in delivering a large volume of pepper to processing and export companies. Wholesaler companies are considered the central hub of distributing pepper whether to cater to domestic or international markets by delivering to export companies to handle the rest which makes them the most influential and profitable with lots of marketing channels under the belt. Additionally, the profit margin acquired can be higher if the pepper berries are sun-dried before distributing to the crowd. There are cases where traders and wholesalers will mix the good portion of pepper berries with the ones with bad in quality obtained at a cheaper price and sell it as good quality pepper as a whole package. This malpractice is often not reported or taken into countermeasures based on the published source.

Export companies are normally dependent on wholesalers for the stable pepper supply and will maintain the long-term relationship by signing an agreement for the continuous transaction of pepper products. 95% of the total pepper production is considered as high-quality pepper and will be prioritized to international markets. The remaining 5% of the pepper production is considered as the low-to-medium quality and normally consumed domestically. The Vietnamese pepper is usually exported in raw form and with the acceptable level of moisture content and the minimum level of extraneous matter as the pepper compound.

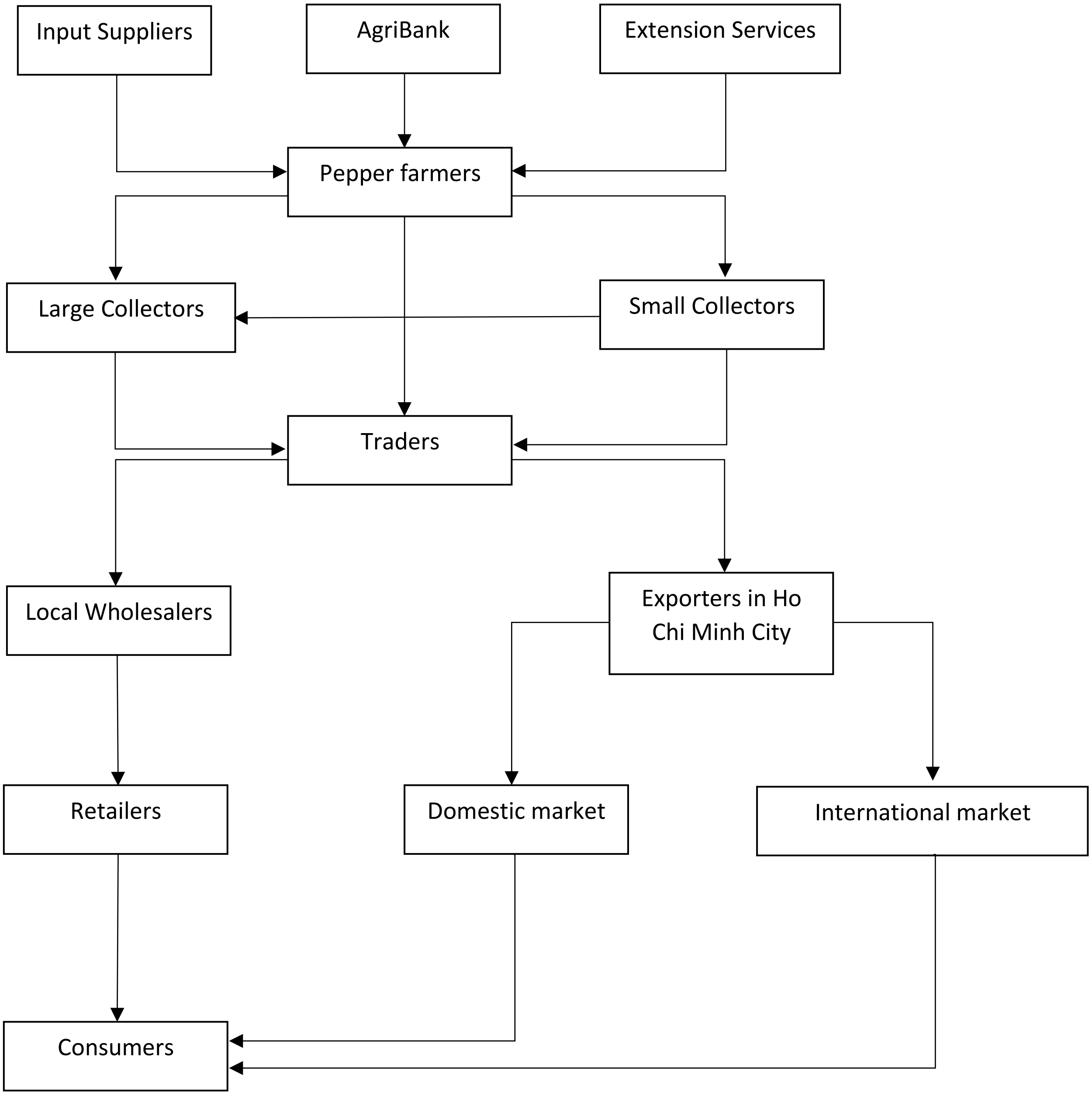


Figure 2.1 Pepper Value Chain of Dak Lak, Vietnam [29, Fig. 10]

2.4.2 Memot, Cambodia [30]

There are approximately 5,400 pepper producers in 6 different communes of Memot district. According to the commune database of Cambodia, 99% of the total pepper producers are dominated by smallholder farmers with a few pepper producers that have 1 to 5 hectares of pepper farming areas. The average size of the pepper farm for each smallholder farmer is around 0.42 hectares. Regularly, the production is reserved to Vietnamese collectors and Khmer sub-collectors who came to villages to seek for the harvested peppercorns. As for the sub-collector, the payment can be delayed until a week or 10 days after purchasing the crops depending on the relationships between farmers. Some members from the Da Memot cooperative will vend the peppercorns to a local private company, Kam Spice, which is built for providing facilitation services instead of selling to collectors.

During the harvesting season, Vietnamese collectors purchase peppercorns in weights of 200 – 300 kg using motorcycles, instant payment by cash. Based on the response of Memot pepper farmers from structural interviews, Vietnamese collectors rarely focus on the quality of pepper as the buying requirements. Moreover, the mixed-quality pepper can be easily sorted out with the majority of processing plants located in Vietnam to do various pepper cleaning and grading. Insignificantly, there are only a few traders existed in Phnom Penh for trading peppercorns from the Memot district and other major provinces.

According to a study team, 1 out of 17 pepper traders in Phnom Penh can be contacted and given the trading info; this accounts for approximately 150Mt per year traded from collectors in Memot district. The rest are either not active or ignore the call although they did publish some advertisements about their pepper business on e-commerce platform including the Alibaba website. Currently, there are only several registered pepper export companies located in Cambodia. The exporters are Olam Company, SELA PEPPER Company, and AMRU Rice Company which are considered having stable operations at the moment. There are some companies such as Long Best Development.Ltd, Tang Huy Pheng company, and ECT Co.Ltd with records that exported pepper products to Taiwan, India, and China respectively.

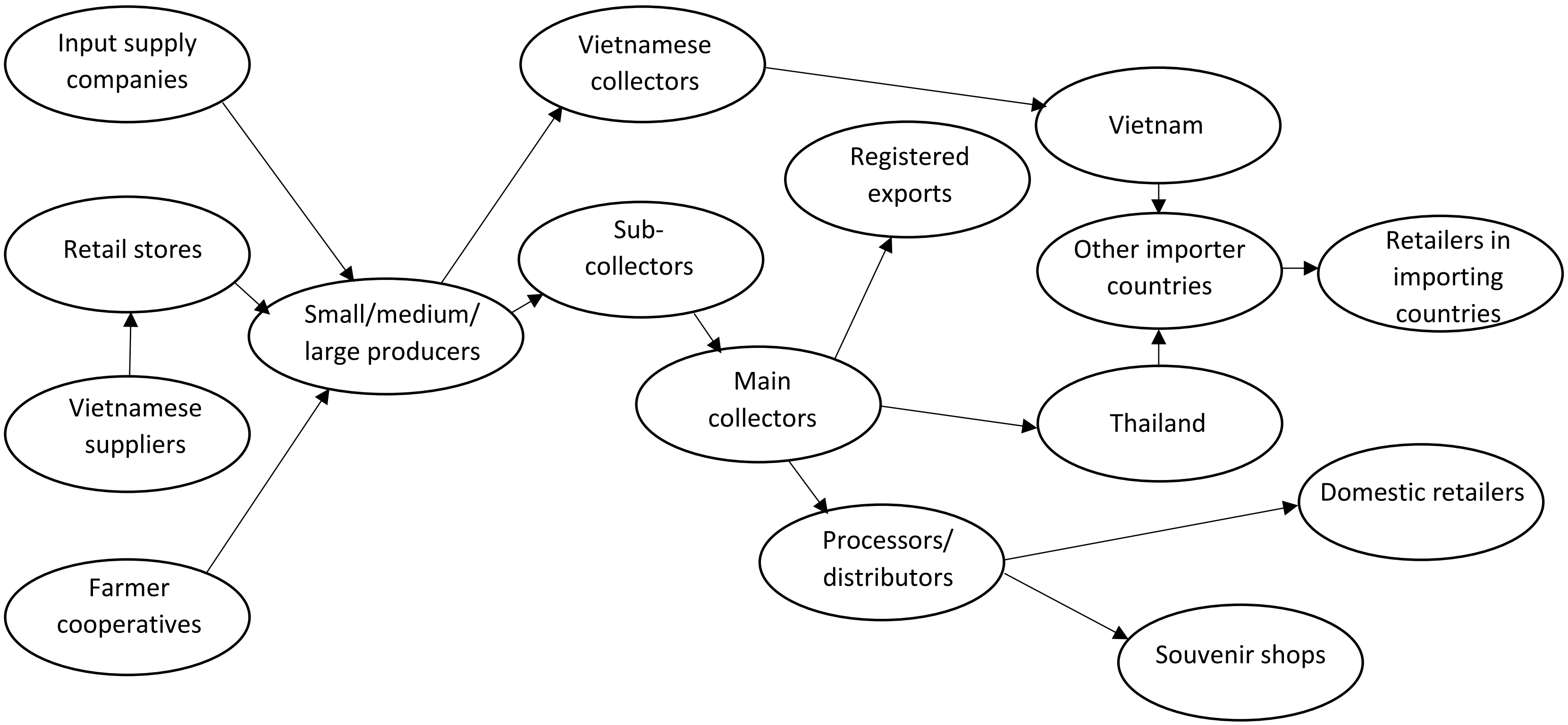


Figure 2.2 Pepper Value Chain of Memot, Cambodia [30, Fig. 3]

2.4.3 Sri Lanka [31]

In Sri Lanka, producers are divided into two separate groups: 93% of the producers are smallholders and the remaining 7% are comprised of estates which are owned by entrepreneurs with sufficient capital for built-in storage facilities. Generally, there are three main types of pepper crops: the green berries, dried black pepper, and the white pepper. According to pepper farmers' experiences, the peak harvesting season is usually situated from November to January but some farmers will pluck it when the berries are still premature due to the fear of crop theft, specifically the green berries. Another leading factor for the premature harvest will be the immediate cash required for business turnover and living survival.

In general, the 3-months harvesting season accounts for approximately 70% of the total harvest per year. After harvesting the pepper berries, the berries will be dried on a cement slab as the drying phase is considered a value-addition to the crops and can be sold at a higher price to the nearby collectors. The pepper farmers will receive the payments based on the quality of the dried-pepper berries from the collectors without any bargaining power.

Besides, smallholder farmers are given the choice which is a situation a trader or processor will approach one of the farmers to negotiate the value of the pepper berries while still on the vine. During the harvesting period, the trader or processor will harvest all the berries on the vine and transport the crops to a drying facility to initiate the processing phase of the pepper crops. The facility is equipped with threshers which removes the spikes and other extraneous matter from the pepper compound to a minimum degree. Eventually, the pepper price offered to the smallholder farmers will not be differed based on the quality since the harvest activity and quality control are entirely handled by the traders or processors.

Collectors are conventionally known as the first intermediary in the pepper value chain. Sometimes, the local collectors are also farmer themselves or rural entrepreneurs that directly obtain the pepper berries from smallholder farmers. Traditionally, there are no perquisites required to become a pepper collector in Sri Lanka. As a result, Sri Lanka pepper collectors are having a competitive role among each other since there are no requirements such as licenses or permits needed for the operation. Collectors will manage the pepper berries that have not undergone the drying phase. Other activities such as cleaning and grading will be carried out as well, then sell all of the processed berries to another subsequent buyer, the trader.

Sri Lanka traders, the second intermediary of the generic agricultural value chain purchase pepper berries from various sources: smallholder farmers, estates, collectors, and leasees. To retain the quality control of pepper, sometimes traders will directly approach pepper farmers or estates to harvest and collect from the producers’ pepper farm by themselves. According to KIIs with traders from Matale and Kandy, this approach is more favorable as village collectors were unable to deal with large quantities of pepper left unsorted from the farmers. Furthermore, the quality of harvested crops is not their top priority as competition is fierce and there are no options and time to choose among farmers that can produce good quality of pepper berries. As stated by Jayalath and Gunaratne, traders are assigned to pack and transport the products to buyers, mostly in Colombo.

As for the wholesaler, the importance is considerably low compared to other pepper value chains as most collectors and traders prefer to make transactions with the exporters. This move is executed to bypass an intermediary or the wholesaler, resulting in higher selling prices with more profit margin obtained by both collectors and traders. Additionally, the exporters are reliable buyers that will always pay on time and purchase at large volumes.

Of all the pepper production from the country, 60% of the total is exported to global markets by exporters whereas the remaining 40% is distributed by the wholesalers and consumed by the locals. The export companies sought pepper products from different sources to prepare shipment based on the amount of order received from foreign buyers. In certain scenarios, the exporters may purchase unprocessed berries from various sources including farmers, estates, and collectors, then undergo the processing activities and export the final products all by themselves but very few exporters may also consider backward integration which comprises the pepper cultivation and drying in large scale.

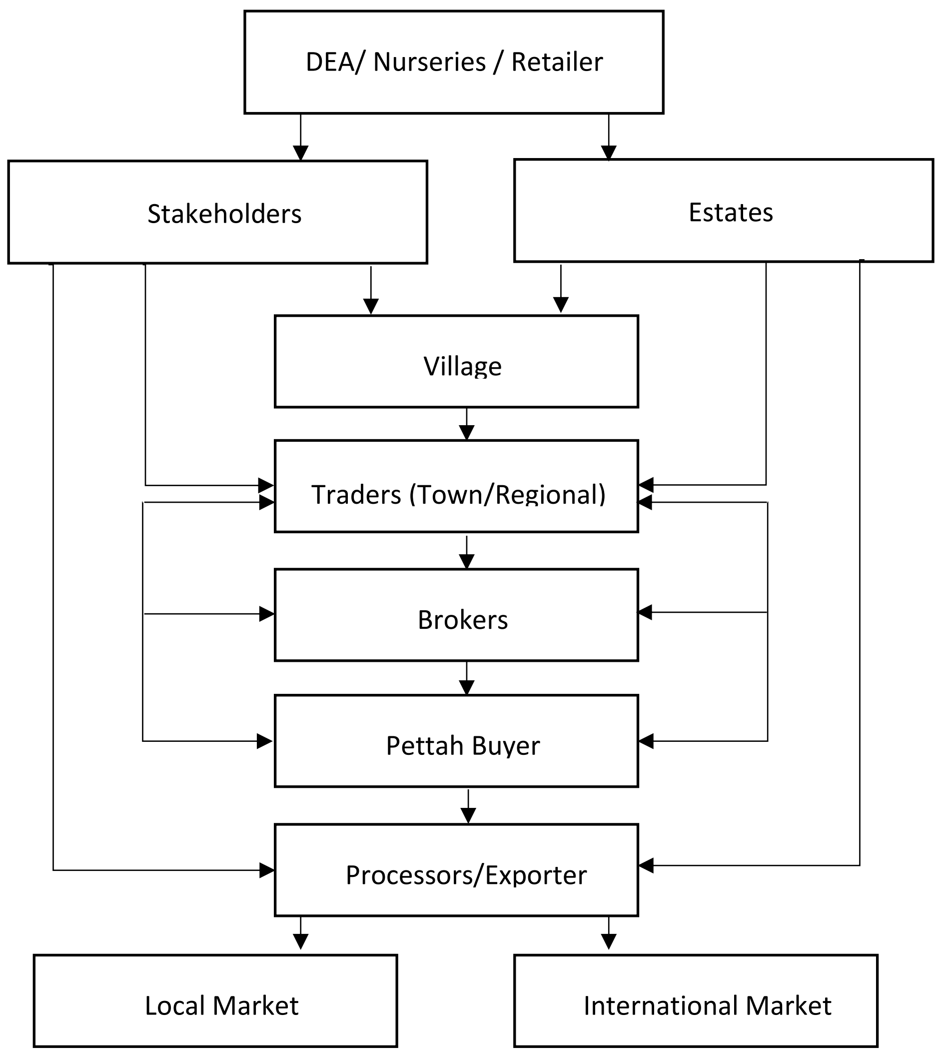


Figure 2.3 Pepper Value Chain of Sri Lanka [31, Fig. 13]

To address plainly, pain points are defined as constraints or difficulties that pepper stakeholders have to encounter during the business operation. As shown in Table 2.3, producer is mainly having the most encountered of pain points, with approximately 10 issues per country. The lack of financial resource and knowledge support are the common entities shared among these countries, thus requires further intervention by local governments to possibly minimize the pain points populated in this stakeholder category. In the next category, pain points are mostly varied, with special circumstances like collectors from Cambodia having competition against Vietnamese collectors, causing an unfair competition for domestic sales. In Sri Lanka, a decent quality of black pepper is considered a scarce commodity as many pepper farmers are willing to sell light berries, a lower grade black pepper, to make a fast buck. As for the pepper-originated country, India is having low incentives for quality differentiation, in conjunction with no appropriate grades and standards to measure the quality. Across international borders, exporters were coherently stating competitive marketspace as their main hurdle. Specific cases from Cambodia such as waiving of procedures and taxes and unprepared credit insurance for the export trades were mentioned as well. Another case is regarding to quality concern, shown in both Sri Lanka's and India's descriptions, with Sri Lanka stating the low standards of black pepper supplied by the intermediaries will cause a cumulative effect, eventually inhibits an export trade while India mentioning the lack of quality awareness towards smallholder farmers will degrade the final product, hence ruins the expectations from international buyers since pepper crops are originated from this country. For supporters, the pain point can be summarized as the lack of provisions, regulatory frameworks, and product standards to all of the stakeholder category. Here, provisions can be financial aids, extension services, processing and researching facilities, and technical supports.

Table 2.3: Pain points from foreign pepper value chains: Cambodia [32], Sri Lanka [31], and India [33]

	Cambodia	Sri Lanka	India
Producers	▪ Inhibit the production flow due to lack of investment capital. ▪ Poor access to innovation and technical skills to maximize production, to control pests and disease and to improve the quality of pepper produce before, during and after harvest. ▪ Low bargaining power to negotiate prices with buyers. ▪ Limited market information and knowledge to utilize the provided information. ▪ Difficult financial access due to high interest rates offered by banks, especially for small-scale producers. ▪ Limited knowledge and experiences in cultivation techniques including the selection of seedlings, selection and use fertilizers and pesticides, and lack of pre-processed techniques. ▪ Instructions for input materials are often labeled in other languages, e.g., Vietnamese or Thai, potentially resulting in inappropriate usage. ▪ Limited access to high-value market, especially export market. ▪ Memot pepper does not have strong supports from government agencies and NGOs.	▪ Climatic changes affecting amount and size of the crop. ▪ High labour cost. ▪ High cost of input materials. ▪ Animal and pest attacks. ▪ Price fluctuation. ▪ Theft. ▪ Inadequate extension services. ▪ Poor attitude among pepper farmers to diversify land and good agricultural practices (GAPs) of pepper cultivation. ▪ Poor infrastructure such as roads and telecom towers. ▪ Minimal processing before selling pepper to the market. ▪ Unaware of the international market requirements and the standards. ▪ Lack of knowledge regarding market prices for pepper. ▪ Little or no linkage between producers and exporters. ▪ Low prices offered by the middlemen. ▪ Lack of government support provided to the majority of smallholder farmers.	▪ Lack of credit accessibility for farming operations. ▪ Rainfall/climatic changes affecting the production of pepper crops. ▪ Pests and diseases. ▪ Lack of proper marketing facilities. ▪ Lack of extension services to smallholder farmers. ▪ Lack of seamless transportation solutions. ▪ Lack of input resources implemented onto pepper crops. ▪ Lack of knowledge regarding the appropriate usage and application of input resources for maximizing returns. ▪ Instability in black pepper prices in marketplaces. ▪ Poor land, irrigation, and soil fertility management. ▪ Lack of economic scale and market bargaining power due to the absence of farmer clubs and associations.

Intermediaries (collectors, wholesalers, processors, retailers)	▪ High fluctuated price of pepper affect purchase plan. ▪ Limited access to pepper cleaning and processing technologies. ▪ High competition with Vietnamese collectors that come to buy at farm gate. ▪ Do not have several registered export partners in Cambodia for purchase contract. ▪ Many farmers were not yet familiar with bank system for their pepper sale. ▪ Limited knowledge of pepper market for processed pepper. ▪ Unfair competition among processors and importers for ground pepper.	▪ Inadequate supply of quality black pepper due to high demand for light berries with attractive prices at farm gate and willingness of farmers to sell light berries to earn "quick money". ▪ Improper storage and processing facilities. ▪ High labour cost for drying harvested peppers. ▪ Little to no cooperation between collectors/traders and wholesalers. ▪ Does not receive any government support or from any NGO organizations.	▪ Small quantities and high transaction costs. ▪ Seasonal business. ▪ Lack of communication, transparency and trust among traders and producers. ▪ Lack of marketing and business skills. ▪ Lack of proper road and procurement infrastructure. ▪ Small number of suppliers. ▪ No grades and standards. ▪ Limited operating capital. ▪ Low incentives for quality differentiation.
Exporters	▪ Requiring pre-paid profit tax and high export costs. ▪ High fluctuated price of pepper affected pepper purchase and sale. ▪ Peppercorns must be transported to Vietnam for cleaning and processing before exporting to consumers. ▪ Illegal pepper trading to Vietnam and Thailand put	▪ Limited quota on pepper exports under ILFTA. ▪ Inadequate supply of quality black pepper products due to low standards of black pepper supplies. ▪ Quality standards of developed countries can act as a trade barrier.	▪ Price competition from other producing countries in the international market. ▪ Higher production of pepper from Vietnam disrupted the international demand. ▪ Lack of proper information dissemination to the producers and lack of control over production based on export demand.

	exporters in challenging selling price of pepper to consumers. ▪ Official export procedures and requirements consumed time and burden export costs for exporters. ▪ Operating and transporting costs are higher compared to neighboring countries. ▪ The Royal Government of Cambodia (RGC) did not yet waive any procedures and taxes for pepper export promotion. ▪ Credit insurance was not yet ready for national trade. ▪ No further strategies for pepper sector development.	▪ Low cost production of Indian essential oils undercuts Sri Lankan oil extracts. ▪ Inadequate testing capabilities of local laboratories to meet stringent requirements. ▪ Lack of market research at the international level. ▪ Few pepper exporters are marketing their products global online platform like Alibaba, which is imperative to reach out to more geographies and clients.	▪ Fluctuations on the price of pepper in international market. ▪ Lack of awareness about required quality for the produce to be exported among the producers and traders.
Supporters (government body, research institute, financial sector)	▪ Absence of research and development strategy, coupled with limited market research and extension services. ▪ Current policy of the government of Cambodia does not prioritize the pepper sector, there is little assistance financially or for technical services. ▪ Quality pepper standards and grading scales are not regulated by the government.	▪ Lack of Good Agricultural Practices (GAP), Good Manufacturing Practices (GMP) and other standards and quality criteria in production and processing. ▪ Inadequate training provided to producers. ▪ Lack of financial support provided to stakeholders. ▪ Lack of primary processing facilities provided by the country.	▪ No data availability on district level, making it difficult for policy makers and support organizations to understand reality and take informed decisions. ▪ Lack of a legal framework to enforce compliance with contracts. ▪ Lack of effective formal institutions to support the sector.

2.5 Blockchain Technology

Blockchain is one of the emerging digital technologies that can be utilized to engage in business transactions, distributed among both parties without the reliance of intermediaries like banks [34]. It is occasionally referred as a distributed ledger technology (DLT); a decentralized system that is capable of recording transactions on immutable ledgers, bundled together in traceable blocks, and has the potential to construct a digitally established value chain finance to address several security gaps such as the misleading data due to manual entries, which is prone to human error and the susceptible modification of data entered into the database for malicious purposes [35]. Therefore, blockchain technology is conclusively reckoned as "Internet of Value" with three substantial pillars: decentralization, transparency, and immutability [36], [37]. In addition, the use of blockchain technology is substantially helping the disintermediation of trust between parties in a supply chain by constructing a single version of truth based on the enforcement of immutability towards the building blocks of the chain and minimizing the risk factor associated with the exchange of resources. Reliably, these security features are being enhanced with the utilization of smart contract; an intermediary feature that helps to automate transaction agreements based on pre-defined conditions, which reduces time taken of approval by legal parties and provides a seamless usage interacting with blockchain technology [38]. Apart from that, blockchain technology also include some additional features that makes it fairly distinctive to traditional databases.

a) Cryptography

Unlike traditional ledgers, there are no third-parties involved but transaction records will be shared among individuals or firms in a connected network [39]. The creator of blockchain technology, Satoshi Nakamoto announced the system behind blockchain as the system-based on cryptographic proof instead of relying upon trust from any third parties to reduce transaction costs and keeping impending approvals to the minimum [40]. Routinely, every transaction will be timestamped and linked in sequence to prevent any outlanders from tampering the data integrity and only can be verified by the selected network nodes with the implementation of cryptographic algorithms [41]. In general, cryptographic algorithms can be classified into three types:

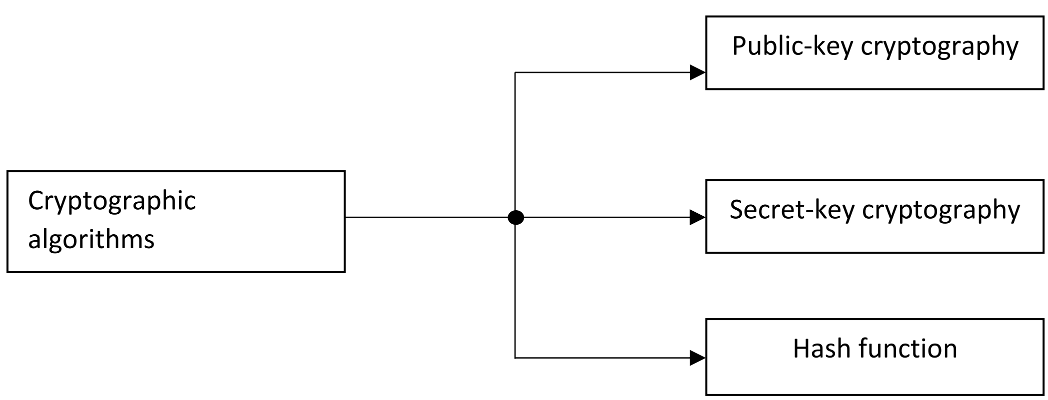


Figure 2.4 Types of algorithms in cryptography [42, Fig. 2]

- Public-key cryptography

  In public-key cryptography, a pair of asymmetric keys is involved in transaction processing: a public key and a private key. Any deployed transactions will be locked with the requester's private key to prevent external tampering from malicious nodes. Subsequently, trusted nodes in the distributed network will be given the public keys to read and authenticate the requester's transaction before appending the transaction to the distributed ledger [35]. Once an element has appended to the nodes' ledger, revocation will be unattainable and only can be viewed as a past activity in the network. Currently, RSA (Rivest-Shamir-Adleman), DSA (Digital Signature Algorithm), and PKCS (Public Key Cryptography Standards) are amongst the popular options for implementing the asymmetric encryption technique in the cryptosystem [43].

  In order to generate the public and private keys for the RSA cryptosystem, two large prime numbers, p and q are selected at random, and multiplied against each other to produce n. Public key, e is chosen at random, where e is greater than 1, less than (p - 1) (q - 1), such that there is no common factor for e and (p - 1) (q - 1) aside from 1 [44]. Then, private key, d is computed such that d*e $\equiv 1$ *mod* (p - 1) (q - 1).

  The computed value, n will be used in the encryption and decryption formula such as follows:

$$E(m) = m^e (mod\ n) \tag{2.1}$$

$$D(c) = c^d (mod\ n) \tag{2.2}$$

  When the client wants to send an N-bit secret message, m to a recipient, the recipient will distribute the public key (e, n) to the client via a transmission channel. The message, m will be encrypted by the client using the encryption function in Eq. (2.1) to produce the cipher text, c and sent to the recipient. The recipient will decrypt the cipher text, c by using his/her own private key (d, n) for the decryption function (refer to Appendix Section [Appendix A] for the sample of calculating decryption key, d), resulting the value of m as the output [45]. The correctness can be further interpreted by inserting the values to the following formula with congruence relation:

$$(m^e)^d \equiv m\ (mod\ n) \tag{2.3}$$

$$c^d \equiv m\ (mod\ n)$$

Therefore, m is equal to $c^d \ (mod\ n)$.

- Secret-key cryptography

  In secret-key cryptography, a single security key is employed for the encryption and decryption of transactions, thus also known as the symmetric encryption [42], [46]. Initially, the reader uses the generated key to encrypt the targeted plaintext into cipher text, then send the cipher text to the intended receiver. The receiver will require the same key from the sender to decrypt the message. By tradition, the security key will be distributed separately from the package via a secure channel to prevent the key from getting compromised by intercepting the cipher text communication channel. This approach may require attacker to put an extra mile in pursuing the security key, eventually complicating the plan of attack [46]. Compared to the public-key cryptography, the speed is greatly favored considering the algorithm behind the symmetric encryption is less complex, which has faster processing and execution for both encryption and decryption. However, it is more susceptible to network attack as the asymmetric encryption does not require to disclose its private key to any network users. Symmetric encryption algorithms such as AES (Advanced Encryption Standard) and Blowfish are commonly used among developers in their network codebase for sharing the security key across the network users [43].

- Hash function

  In hash function, its functionalities are slightly dissimilar to the above approaches. The main differences are the omission of key utilization for security operations and the original message is irreversible. Hash functions are mostly used to protect the integrity of data packets or digital files by computing message digests or checksums as the output of the mathematical operation [42]. Prior to data transmission, the sender will first generate the message digest from its original file, then transmit those two objects to the intended receiver. Once received, the receiver will do the same computation and undergo the comparison against the received digest. If the checksum is the same, it signifies the file is unaltered and maintains its originality. If the result is not equal, the file is considered as a compromised file and further investigation will be conducted. Some legacy examples of hash function are the MD5 (Message Digest 5, *obsolete due to its vulnerabilities and possible collisions*) and SHA (Secure Hash Algorithm) [46], [47].

b) Peer-to-peer (P2P) synchronization architecture

   Most of the distributed network such as blockchain was wholly designed based on the peer-to-peer (P2P) paradigm. Practically, the storage and access load requirements per peer is much lighter with a P2P network due to the reliance on their own localhost storage rather than manoeuvring the network traffic to reach a centralized Google-like server farm [48]. Hence, the P2P network elicits as a more feasible and powerful technique for information sharing and transaction management. In conjunction with blockchain system model, every node on a P2P network is required to share information and upkeep ledgers of past transactions in the model of both client and server at the same time. Therefore, network nodes can achieve consensus on the current or non-faulty state and ensure the transactional information is settled consistently in their own distributed ledgers [49].

c) Consensus Mechanisms

One of the prominent features from blockchain technology is the agreement among a set of distributed nodes for linking new data blocks to the appropriate chain sequence of the verified transaction, also known as the consensus algorithm [50]. Fundamentally, consensus algorithms are the essential operating feature in distributed ledgers, which allows the system to survive in occasions such as failure of certain nodes within an acceptable range. They play the utmost and decisive role in maintaining a reliable large-scale system [50]. Besides, they are considered to be mechanistic and automated, which provide the trustless software mechanism for transacting parties that do not need to trust each other [51]. The first blockchain consensus algorithm that was being employed is Proof of Work (PoW) and commonly used by cryptocurrency platforms such as Bitcoin and Ethereum [52], [53].

2.5.1 Data structure of Blockchain

Figure 2.5 shows that each block has its own hash value obtained through cryptographic hash function or block hashing, a previous hash from the antecedent block, and a set of transactions [40], [54]. Conventionally, hashing will accept inputs of an arbitrary length and output random alphanumerical characters in a fixed-length string. All generated output is unique and contained a footprint to determining the original value by key mapping.

With block hashing, it becomes cryptographically more secure by establishing sequential order of the concatenated blocks based on timestamped transactions and prevent structural changes such as inserting an unacknowledged block in the middle of the blockchain. An instance of hash function is the Secure Hash Algorithm 256 (SHA256), which is frequently used in most distributed networks, including the Bitcoin network [55], [56].

Internally, proposed transactions will have to undergo the full consensus procedures among network nodes before it can be stored in the chain of hashed blocks. The complete set of hashed blocks is basically a digital ledger that is shared among non-faulty nodes to achieve data coherency for every validated transaction. Eventually, transaction will be allowed to execute in the system upon reaching majority consensus in the blockchain network (BCN) [54], [55].

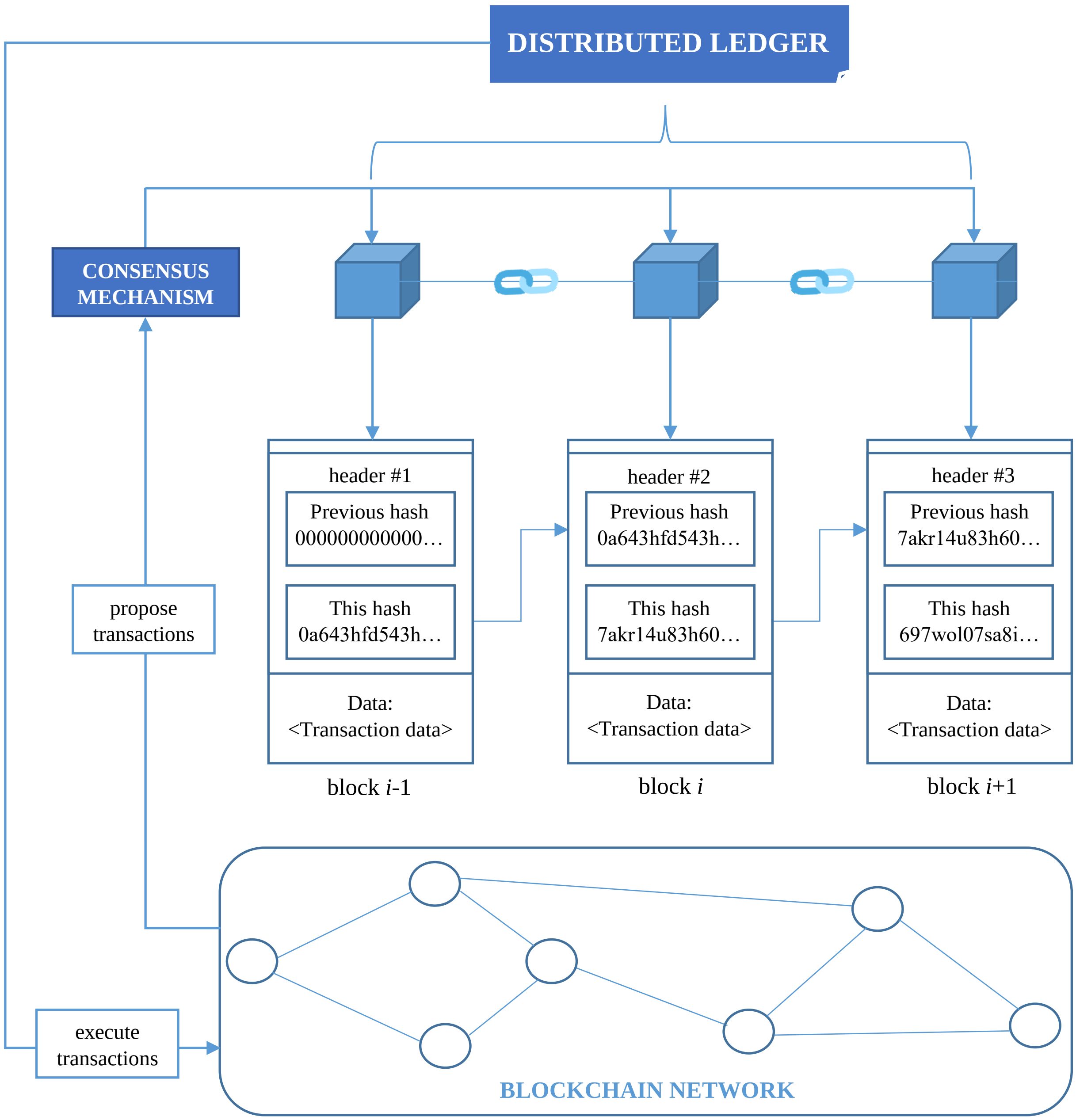


Figure 2.5 An example of underlying structure of a typical blockchain network [55, Fig. 3]

2.5.2 Blockchain-Agricultural Value Chain

Blockchain technology can play a vital role in providing conveniences and monitoring the status of harvested crops within the agricultural value chain. For instance, when a batch of pepper crop leaves a farm, the details of its origin would be registered in a block of the chain. As the batch of pepper crop passed to another stakeholder of the chain, the transfer details will be logged in the subsequent block and connected to the previous block. Hence, when the consumer finally received the pepper products, the blockchain will consist of the entire movement of product flows within the chain based on linked blocks sequentially, which provides full transparency and ensure the sustainability of the product [57]. The records of the previous transactions and identities of the stakeholder and customer of the chain, can be used to target areas with higher demands for the product and make it more accessible with consistent availability or increasing the amount of production periodically. Moreover, the market pricing will also be disclosed to all stakeholders of the agricultural value chain who had joined the BCN, thus providing fairness to small-scale producers, who are mostly affected by profit deficiencies due to the lack of bargaining power in the chain [58].

Technology provides the opportunity for smallholder farmers to decrease their dependence on middlemen, intermediaries, or third-party agents to supply the food product to the local and international stores, thus reducing transaction costs. Furthermore, the crop pricing, date of production, location timestamp, associated contracts, and other qualitative aspects will be recorded in the immutable chain of blocks shared within the BCN, transparently maintained, and accessible to all participated stakeholders and also customers by scanning the QR code labeled outside the packaging goods to ensure food safety and reduce food frauds [59]. For instance, the lid of the pepper packaging will be laminated with a QR code that can be scanned to conform the product integrity. Once the QR code is peeled upon opening the package, the antenna strip will be disconnected and deemed as a useless state. This precaution can ensure the content will always be authentic and unable to replace the previous fillings from the packaging, thus reducing the case of food frauds [60].

Regarding trade finance across global markets, blockchain technology can be leveraged to improve the efficiency and security of digital transaction. Without blockchain technology, several checkpoints may be required for a successful trade. For example, within Sarawak’s pepper trade, a consortium blockchain can be utilized to simplify the complexity of exchange settlements. Verification of documents including the Bills of Lading, Letter of Credit, and Grades Certification of Pepper can all be validated online with automated procedures known as smart contracts, which trigger when predetermined terms and conditions are met between buyers and sellers [61].

2.5.3 Key Challenges and Limitations of Blockchain

Although blockchain technology sounds promising, it is still facing several technical difficulties and constraints. First of all, the major limitation that relates to the adoption of blockchain technology is its scalability. In a legacy transaction processing network, thousands of client transactions can be finished within a second [62]. Contrarily, public blockchains such as Bitcoin and Ethereum are unable to compute transactions at a similar rate. The Bitcoin network can manage within 3 to 7 TPS while Ethereum network can perform at a slightly higher rate, around 15 to 20 TPS, making them relatively a non-viable solution in large-scale applications [63]. These outcomes are mainly affected due to the implementation of PoW that requires miners to solve cryptographic hash puzzles within a substantial amount of time. To increase the TPS, a solution known as the 2-layer protocol was introduced by Fajri and Mahananto [64]. The protocol is able to manage incoming transactions outside the main layer with the finished results be returned to the main layer and recorded into the distributed ledger.

Computationally speaking, these ongoing platforms have been following the "hard to create, easy to verify" principle, which means the mathematical problem to hash transactions is somewhat difficult to solve, but radically effortless to verify the answers [65]. On a prior condition, miners who wish to be rewarded may need to find the valid solution for the given problems with the higher hash rates before they can append the verified transactions into the concatenate blocks [66]. As for the tradeoff, electricity and hardware requirements for competitive miners to be the fastest in the BCN will be exceedingly high.

A recent study suggested that with a huge network like Bitcoin may require the electricity requirement of an entire country such as from Ireland (3.1 gigawatts) and Austria (8.2 gigawatts) to hash blocks properly [67]. Fortunately, there are some alternatives that can replace the current PoW methodology with fewer electricity and hardware requirements, including PoS; the next major iteration of Ethereum, dubbed Ethereum 2.0 [68], Proof of Authority (PoA), and Byzantine Fault Tolerance (BFT) algorithm [37].

2.5.4 Blockchain Implementation in Agricultural Industry

Blockchain technology has been widely popular over the past few years, whether is through Bitcoin investors or tech enthusiasts who are interested in the way of handling data verification through the consensus mechanism. Lately, this revolutionary technology is digitalizing traditional agricultural value chains by tech startups, NGOs, and governments around the world. It is being used to gain commodity traceability and management, create high-value markets for smallholder farmers, easier access to capital and microloans, and secure internet transactions without any third-party verifications [69]. Several companies such as AgriDigital [70] and AgUnity [71] have already been taking the initiatives to leverage blockchain technology for their cloud-based agricultural platform and conducting pilot studies in places such as Australia, Indonesia, and Kenya [59].

2.5.4.1 AgriDigital

Since 2016, AgriDigital has been offering the Australian grains industry software services [72]. It was later officially announced and executed the world's first settlement of the sale with 23.46 tons of grain on its blockchain platform [73]. The AgriDigital platform was built based on Quorum blockchain architecture, which allows to create private transactions by using different consensus algorithms, generate digital titles to a physical commodity, and able to execute auto-execute payment using Ethereum Smart Contracts [74].

Within the permissioned blockchain, three parties are required to fill the slots to initiate: the grower, a grain trader, and Rabobank or the financial. Once the transaction has been completed atomically between the grower and trader, smart contracts resided in the application layer will automatically execute the transfer of commodity title and amount from growers to Rabobank in exchange for payments made through the buyer. In return, the Rabobank will be repaid by the buyer when it was prepared to transact the commodity to third-party buyers [59]. All payments were circulated systematically thanks to the automated settlement of the purchase and forward sales contract system with Rabobank-backed digital currency as the transaction entity and can be easily converted to the traditional Australian dollar [37].

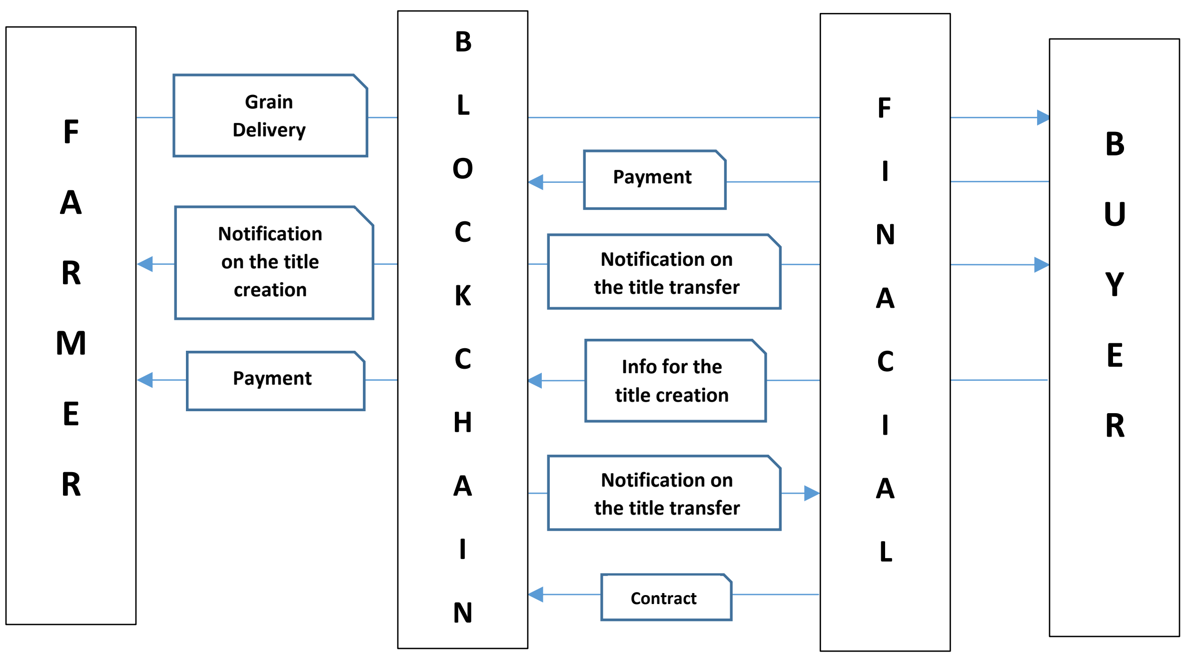


Figure 2.6 The collaboration between the farmer, buyer, and financier with the help of blockchain platform [75, Fig. 5]

Figure 2.6 illustrates the pilot conducted through the well-established Quorum blockchain; a testing platform for bulk transactions and entitlement transfers between farmers and traders with Rabobank, the world’s leading agricultural bank being centered as the financial entity in the distributed network [75]. To start off the grid, a grain trader is firstly required to make purchasing agreements with the sole financial. The financial entity will advertise the title creation to the blockchain and purchase grain assets from notified farmers. Once the commodity has been delivered, an embedded smart contract will be executed for transferring out the digital title from the farmer along with the given payment on the blockchain and off-chain. As for the grain trader, they can be allowed to postpone their digital payment to the financial until a third-party buyer approach them for the commodity. After selling out the commodity, another smart contract will be prompted for payment settlement and the transfer of entitlement from the trader to the third-party [75].

2.5.4.2 AgUnity

AgUnity Ltd, an Australian startup has been internationally recognized, including by the Gates Foundation, Asian Development Bank, and UNICEF for its outstanding achievement in transforming farming cooperatives from Papua New Guinea and Kenya with given value and was crowned 'Agripreneur of the Year' at Future Agro Challenge in Turkey [76]. Since most farmers do not own a smartphone, AgUnity provides a $30 smartphone to participated farmers preloaded with its blockchain application, cleped AgriLedger [71]. The application is built based on MultiChain blockchain architecture and has the executable called '*multichaind-cold*' from its JSON-RPC-API, which enables the mobile application to operate offline in the rural environment until the internet connection is re-established [77], [78]. Objectively, it was built to record and manage business transactions using blockchain technology. It is foundationally built on a distinct concept: to develop trust relationships within African and Asian agricultural cooperatives. It is also designed for illiterate farmers to use on both mobile and tablet devices. Some available areas that have been using the application are Kenya (sugarcane and wheat), Papua New Guinea (sea cucumber and virgin coconut oil), Columbia (cocoa and coffee), etc.

Before the actual release of the blockchain application, AgUnity had spent months with Kenyan communities in regards to their agricultural challenges and acknowledge their necessities to improve their supply chain management (SCM). It was later identified that their persistent pain points are the food production inefficiency and the deficiency of trust between smallholder farmers and agricultural cooperatives. The production inefficiency had led up to 50% of loss in crop value between the harvest and sale by smallholder farmers. Moreover, smallholder farmers are required to pay inflated prices for essential supplies and difficulties to access the high-value market, market price information, credit services such as insurance and banking. Although small-scale farmers have been in farming cooperatives for a while, the lack of trust and feasible audit systems are prone to corruption and inevitable multiple human errors while doing monthly compilation reports. As for the intervention of mobile application into the supply chain, the illiteracy of knowingly to navigate the mobile application is substantially crucial amongst Kenyan communities. Upon receiving constant feedback from the users, it was concluded that semi-abstracted graphics with supported-native languages and simple UI configurations are considerably helpful, less confusing, and able to motivate users on utilizing full-features provided in the mobile application [79].

2.6 Byzantine Fault Tolerance (BFT)

BFT is described as a distributed system that is capable of tolerating a class of failures originated from the Byzantine Generals' Problem. Thus far, the Byzantine fault is considered the onerous failure mode to deal with as compared to other class of failure modes. For instance, a node can still pose as having honest data while providing arbitrary data or faulty decision to the consensus network. Without the Byzantine Fault Tolerance in existence, a peer can simply post and transmit erroneous transactions that will render reliability issues to a distributed network. Furthermore, there are no authorities to resolve the occurrence and suspend the malicious node for compromising the consensus network [80].

To solidify a trustless system for a blockchain platform, Byzantine-based consensus algorithms are deployed and govern the continuous operation of the BCN despite the arbitrary interruption by the Byzantine nodes. The BFT-enabled system can allow $\frac{1}{3}$ of the replica nodes to be faulty, then refreshed their states with proactive recovery schemes. However, such schemes may not be able to eradicate certain specific issues such as the prolonged process of repairing the compromised replica and the re-synchronization of active replicas to serve the network while waiting for the recovery of the faulty nodes. Therefore, the solution provided by current BFT consensus algorithm may not work well in a large-scale BCN of the future, if the issues are still remained and without further optimization to the consensus mechanism [81].

2.6.1 Byzantine Generals' Problem

Most consensus algorithms were derived based on an existing problem known as the Byzantine Generals' Problem [82]. It was firstly described in 1982 by Lamport, Shostak, and Pease [83] as a logical dilemma of a group of Byzantine generals that may have communication constraints to decide on their next approach of the game plan in a paper at Microsoft [83]. The scenario can be pictured with several divisions of the Byzantine troops camped at different corners of the enemy's lair.

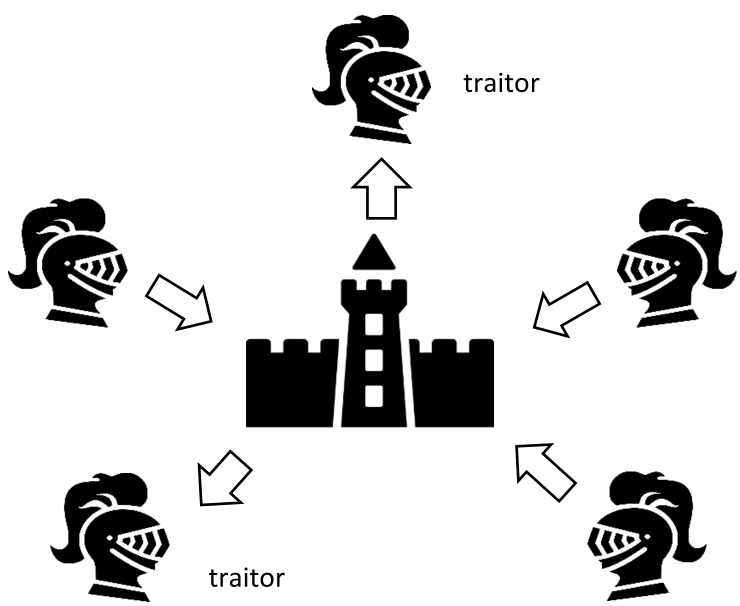


Figure 2.7 Byzantine Generals' Problem:

The uncoordinated attack by the Byzantine Generals

Figure 2.7 illustrates that each division has their own commanding general and must decide on when to strike their targets. In order to synchronize their attacks, one of the generals will become the commander of every divisions and require to dispatch a messenger to inform other generals about the designated time of attack. With every general agreed on the synchronized plan, the messenger will return to the dispatcher waiting for the initiation. Unfortunately, some of the generals may decide to betray the commander, which causes certain troops to not follow the designated time of attack [80]. In the end, divisions that followed the instruction from the commander were all captured by the enemy due to the lack of cooperation among generals.

Based on the given scenario, the next appointed commander must implement an algorithm to reaffirm all generals to be loyal and will obey to the same plan of action, or in the worst-case scenario, to ensure only a small number of traitors to adopt their schemes without sabotaging the ongoing operation. In a peer-to-peer network, the agreement for the time of attack is basically the consensus protocol that is distributed through the friendly and tyrant nodes, or Byzantine nodes which mislead other nodes of the network [84]. In order to cope with Byzantine nodes, there must be at least $3m+1$ generals with m as the placeholder for the total number of traitors that exists and is needed to cope in the network [83]. If there are more than $\frac{1}{3}$ of Byzantine nodes in the network, consensus will not be achieved properly and the network will be compromised indefinitely [85].

2.7 Example of Blockchain Consensus Algorithms

2.7.1 Proof of Work (PoW)

Proof of Work (PoW) is known to be the earliest consensus mechanism to be deployed in a public blockchain. The consensus is mainly contributed by its Sybil resistance; a mechanism that negates one user or a group to populate the network with synthetic identities. In practice, every user must undertake a considerable amount of computational work in order to be qualified as an honest node operating within the BCN, resulting in a hefty price to carry out a Sybil attack [86]. It was researched and coined as a cryptographic protocol by Jakobsson and Juels in 1999 [87], until a pseudonymous creator, dubbed Satoshi Nakamoto introduced the first BCN, or the infamous Bitcoin network in 2008, which employed the PoW consensus model as the fundamental layer of the decentralized system [88].

In Bitcoin, nodes are able to dynamically join and exit, at the same time, preserved anonymous identity when performing any transaction activities. Apart from client and server nodes or both, there is a special node co-existed with these P2P nodes, known as the mining node or miner. These miners are required to compete against each other by being the first to solve the generated mathematical problem in order to grant the position to verify the pending transactions, append those verified transactions as a block to the blockchain, and be rewarded with Bitcoin as incentives from the system [89]. Because of miners, the decentralized network is able to withstand notorious cyber-attacks that commonly happened in centralized servers such as the Distributed Denial-of-Service (DDoS) attack. However, miners that are being competitive will have to acquire high-end hardware and manifest huge computational power in order to speed up the process of finding the solution for the cryptographic puzzles and be frequently selected to add blocks filled with transactions to the blockchain [90].

2.7.2 Proof of Stake (PoS)

Instead of miners, Proof of Stake (PoS) relies on validators to mine or validate transactions, depending on how much the validators can deposit their current possessed digital assets or coins into the system [91]. It was created in year 2011 by another pseudonymous developer, dubbed Sunny King and emerged as a plausible replacement due to its cost-effective approach compared to the existing PoW consensus mechanism, which is heavily utilizing on computational resources for solving cryptographic puzzles and required a costly investment on server-like hardware to provide security measures for the BCN [90], [92]. In PoS, whoever stakes the highest coins will be chosen to propose and validate transactions and blocks into the distributed ledger. At the end of the blockchain concatenation, the validators will receive recompenses in proportion to their stakes [90]. Similar to PoW, PoS is also Sybil resistance. The attackers have to shell out a certain amount of stakes for each fake identity created within the BCN, thus making a Sybil attack an expensive and uneasy operation.

2.7.3 Practical Byzantine Fault Tolerance (PBFT)

A practical state machine replication algorithm was derived and proposed by Castro and Liskov [93] in 1999 at Massachusetts Institute of Technology (MIT), entitled the Practical Byzantine Fault Tolerance (PBFT) [94]. As the paper presented, the algorithm can tolerate Byzantine faults and offer 2 core attributes, liveness and safety in the asynchronous environment such as the Internet, providing at most $[\frac{n-1}{3}]$ out of a total *n* replicas that are concurrently faulty or exhibit arbitrary behavior [93]. The liveness attribute ensures the retrieval of replies to the requested clients while the safety attribute will make sure only non-faulty nodes can execute the requests simultaneously [7].

A distributed system can achieve consensus via its message transfer mechanism and underpins the quorum theory in the transmission protocol, which requires the distributed transaction to procure a minimum number of votes in order to perform the requested operation by a client [6]. As a result, the PBFT algorithm is widely known as the main consensus algorithm for permissioned blockchain due to its reliance on voting-based mechanism that helps to generate higher throughput transactions when comparing to other consensus methods, including PoW and PoS, which ubiquitously implemented in public blockchains and consumed a considerably high amount of computational power to solve cryptographic puzzles based on the mining-based mechanism of PoW and stake requirements from PoS [95].

However, its scalability may pose a downside to the gradual expansion of the network as the waiting time will increased due to the quadratic time complexity of the algorithm; $T(n) \in O(n^2)$ to the latency of the data communication [6]. In addition, nodes are not allowed to simply participate or exit without restarting the whole system, which obstructs the dynamic synchronization of the total number and state of nodes in the distributed network [8]. Table 2.4 summarizes the properties exhibited from each consensus algorithm.

Table 2.4: A comparison of Proof of Work (PoW), Proof of Stake (PoS), and Practical Byzantine Fault Tolerance (PBFT) blockchain consensus protocols [6, Tab. 1], [63], [96]

	PoW (Bitcoin)	**PoS** (Ethereum)	**PBFT**
Fault tolerance (%)	50%	50%	33%
Latency	High	High	Good, if network is small
Node identity management	Open, freely accessible	Open, freely accessible	Member management
Scalability (*number of nodes able to tolerate*)	Excellent	Excellent	Bad
Throughput (*transaction per second*)	7 TPS	15-20 TPS	Thousands of TPS

2.8 System Model of PBFT

A conventional PBFT network comprises of network nodes that are sequenced from 0 to *n-1*, where *n* is the total number of nodes and can tolerate a maximum of *f* nodes, a placeholder that symbolized faulty replica nodes in the distributed network [94], [97]. This is to say that the faulty nodes will always be equal or lower than the calculated value on the right and will not exceed 1/3 of the total consensus nodes in order to have a successful transaction requested by the client. Eq. (2.4) describes the relationship between *n* and *f*.

$$f \leq [\frac{n-1}{3}] \tag{2.4}$$

There are three main components: view, primary, and replica resided in the PBFT network. As time progresses, the ongoing network will be obligated to traverse through a series of these ascending views. A view can be represented as a process of choosing replica nodes to be the leader or the primary node of a peer-to-peer (P2P) network for a definite time [94]. Nodes will be taking turns to be elected as primary node to initiate the voting process indefinitely [9], [97], e.g., a five-node network with node 0 as the primary in view 0 and node 4 as the primary in view 4 as the end of the first cycle. Upon reaching view 5, it will revert back the leader position to node 0 as the initiation of the second cycle. When lost count due to further cycles, Eq. (2.5) can be used to determine the next leader based on the view number, *v* and the total nodes in the distributed network, *n* [94]. By reusing the previous example, view 6 in a five-node network means node 1 will be the leader as 6 modulo by 5 equals to the number 1.

$$v_p = v \bmod n \tag{2.5}$$

2.8.1 Normal-Case Operation

To append transactions into concatenate blocks, a primary node must first be appointed, then receive a request from the client that invoked the service operation and initiate the 3-phase processing protocol, namely the pre-preparing, preparing, and commit phases to gain consensus and coordination from replica nodes in the distributed network [98]. The following diagram depicts how a transaction is being processed and verified between non-faulty nodes.

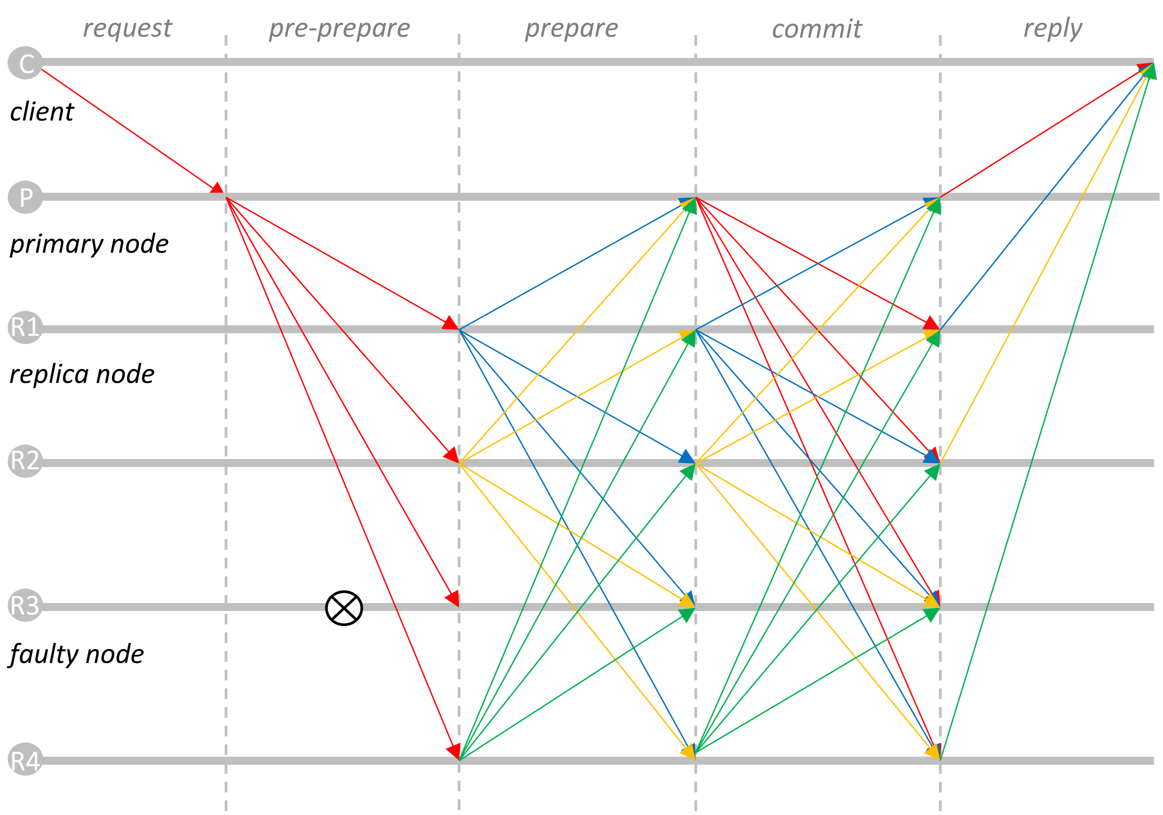


Figure 2.8 The communication pattern of Practical Byzantine Fault Tolerance (PBFT) in a five-node distributed network [93, Fig. 1]

As shown in Figure 2.8, the primary node will broadcast PRE-PREPARE messages and will piggyback the ordered request from the client to all of the replica nodes. The PRE-PREPARE message is structured as $<$ PRE-PREPARE, v, n, $D(m) >_{\sigma_p}$, where:

- v is the view,
- n is a sequence number assigned by the primary node to the client request,

- *m* is the client's request,
- *D* is the message digest for the client's request, which was designed to protect the integrity of the message by using cryptographic hash function to encrypt and prevent malicious alterations when sending through the communication channel [99], [100],
- and σ_p is the digital signature inscribed by the primary node as a proof of authenticity [101].

After receiving the PRE-PREPARE messages, the replica nodes will verify the approved ordering from the primary node and will each broadcast the PREPARE message in the form of < PREPARE, *v, n, D(m), i* $>_{\sigma_p}$ as a ready-to-commit state indication, where *i* indicates the numbering or position of the replica node. Once consensus nodes have received more than or equal to *2f+1* PREPARE messages, they can start to commit the client's request into their message log and broadcast the COMMIT message or < COMMIT, *v, n, D(m), i* $>_{\sigma_p}$ within the distributed network [93].

In order to confirm the request, a replica node must receive *2f+1* COMMIT messages with the right signatures and belongs to the same view. The client will eventually be given *f+1* responses from the distributed nodes, which signifies the transaction has been successfully executed and will be recorded into the distributed ledger. Otherwise, the request from the client will require to be retransmitted by electing new leader to initiate the 3-phase processing protocol [102].

2.8.2 View-Change Protocol [93], [100]

When a primary node failed to coordinate network nodes for gaining consensus or unable to fulfill the ordering from a client, an embedded system protocol known as the view change protocol will be executed. By running the view change protocol, a re-election of the primary node will be held for the next node to become the leader, then proceed to the voting procedures to achieve the quorum among the replica nodes.

Prior to the incident, replica nodes will start a timer upon receiving a client's request from the primary node. Once the request has been executed and responded back to the client, the timer will be stopped immediately. In contrast, an expired timer indicates suspicion of their leading operative and will prompt to request for a view change. Resultantly, replica nodes will stop accepting messages and will multicast the VIEW-CHANGE message within the entire network.

In PBFT, the purpose of view change initiated by consensus nodes is to ensure liveness or the continuous operation of the system when the primary node failed to conform a propose transaction, thus unqualified to be the network leader for the next view. To initiate the protocol, non-faulty replica nodes, *i* will need to adhere the sequence number of committed requests across views to preserve additional safety. Upon timeout, replica nodes will multicast the VIEW-CHANGE message or < VIEW-CHANGE, *v+1, n, C, P, Q, i* $>_{\sigma_i}$, where:

- *n* is the sequence number of the last stable checkpoint *s*,
- *C* is a set of checkpoint messages proving the correctness of *s*,
- *P* is the information regarding the request that have prepared in the previous view,

- and Q the information regarding the request that have pre-prepared in the previous view.

During view-change, replica nodes will stop accepting regular messages other than view-change, new view messages, and checkpoint messages. In the meantime, replica nodes will also remove the PRE-PREPARE, PREPARE, and COMMIT messages of the previous view from their message logs since the messages that are related to an unsuccessful transaction cannot be fulfilled in the current view.

When receiving VIEW-CHANGE messages, non-faulty replica nodes will send an message packet as an acknowledgement in the form of < VIEW-CHANGE-ACK, *v+1, i, j, d* $>_{\sigma_{ip}}$ to the primary node of the subsequent view or *v+1*, where *i* is the identifier for the sender of VIEW-CHANGE-ACK message and *j* is the replica node that send the VIEW-CHANGE message to the current sender. The new primary node will then broadcast the NEW-VIEW message or < NEW-VIEW, *v+1, V, O* $>_{\sigma_i}$ to all replica nodes upon receiving a minimum of *2f* valid view-change messages from them, where *V* contains a set of valid view-change messages and *O* is the new pre-prepared message for re-executing the client request.

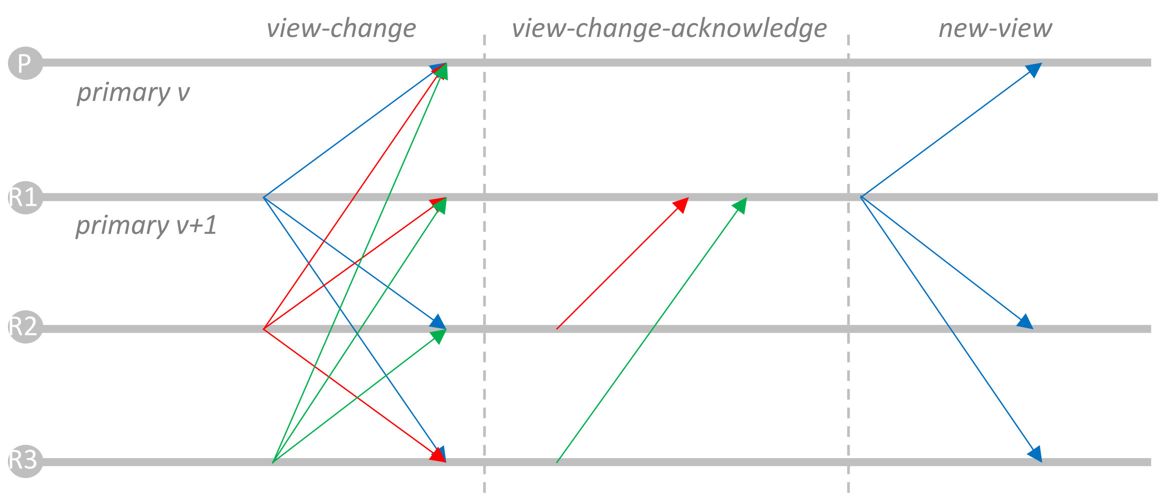


Figure 2.9 The communication pattern of PBFT view-change protocol [100, Fig. 2]

2.8.3 Examples of Proposed Algorithms derived from PBFT

2.8.3.1 EigenTrust-Based Practical Byzantine Fault Tolerance (T-PBFT) [9]

In T-PBFT, EigenTrust model is integrated into the existing PBFT consensus algorithms to enhance security measures by evaluating the global trust value of every distributed node resided in the network. The global trust value is treated as a baseline by allowing the eligible nodes to participate a consensus group. As a result, the operating P2P environment will be more efficient since the nodes located in the consensus group are only allowed to participate the consensus decision-making instead of all distributed nodes in the network that may also prompt to more faultiness during the consensus process. The same goes to primary nodes as higher trust value from the consensus group will be selected to join the primary group, which helps to reduce the occurrence of view changing even when one of the primary nodes decided to become rogue and will be replaced instantaneously. To simplify, the primary group is tasked to build, record, and substantiate the newly generated block to the tail of the blockchain, in addition to reduce the probability of initiating the view change protocol resulted by the single primary failure.

When new block is appended to the chain, verified transactions placed in the block will be immutable, subsequently calculating the global trust value of all participated nodes in the consensus procedures. Conclusively, the global trust value is the main touchstone for allowing participated nodes to join either the consensus or primary group. The figure below depicted the normal case operation or the consensus procedures of T-PBFT, where *O* is a group of nodes that will not participate the voting process.

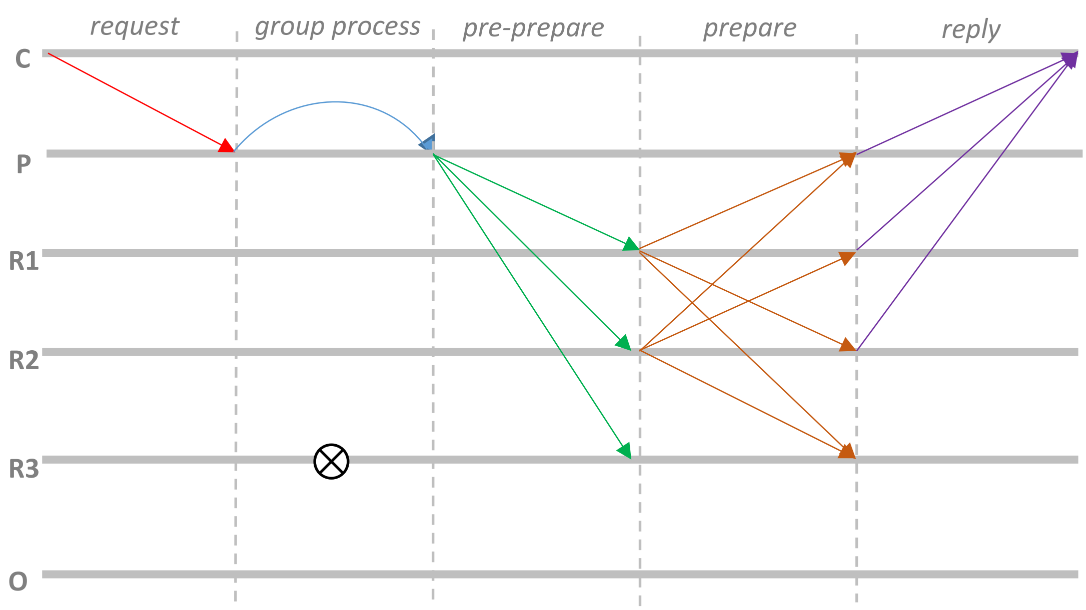


Figure 2.10 The communication pattern of EigenTrust-Based Practical Byzantine Fault Tolerance (T-PBFT) [9, Fig. 4]

2.8.3.2 Scalable Dynamic Multi-Agent Practical Byzantine Fault Tolerance (SDMA-PBFT) [6]

In SDMA-PBFT, the concepts of agent and hierarchical technology are used in the distributed environment for transactions. Firstly, the system is divided into layers with several areas. Each area is governed by an agent node, which is treated as the primary for the corresponding cluster. The agent nodes will be the representative of supervising the ongoing PBFT consensus algorithm from their respective area and compiled the total response from consensus nodes to the upper agent nodes. The conduct of PBFT consensus algorithm will be initiated by each of the primary of the area after receiving the transaction request by the client. Since there are different layers of the system, the agent from the first layer will multicast the pre-prepare to the bottom layer of agents of each area. Multicasting of the client request will be repeated till the end of the layer has reached.

To construct different layers of the system, a spanning tree generation algorithm is required to populate the network nodes in a hierarchical structure. This structure can help to distribute the total amount of nodes required to be facilitated by the primary node. In terms of security level, the probability of network attacks can be reduced to the minimum as there are multiple agent being selected to govern the consensus nodes in several areas, which will prevent the consensus process to be halted for view changing due to the compromise of a single primary in the original PBFT consensus algorithm. In addition, the agent node will be re-selected occasionally to scramble the agent node that have been targeted by attackers in a definite amount of time.

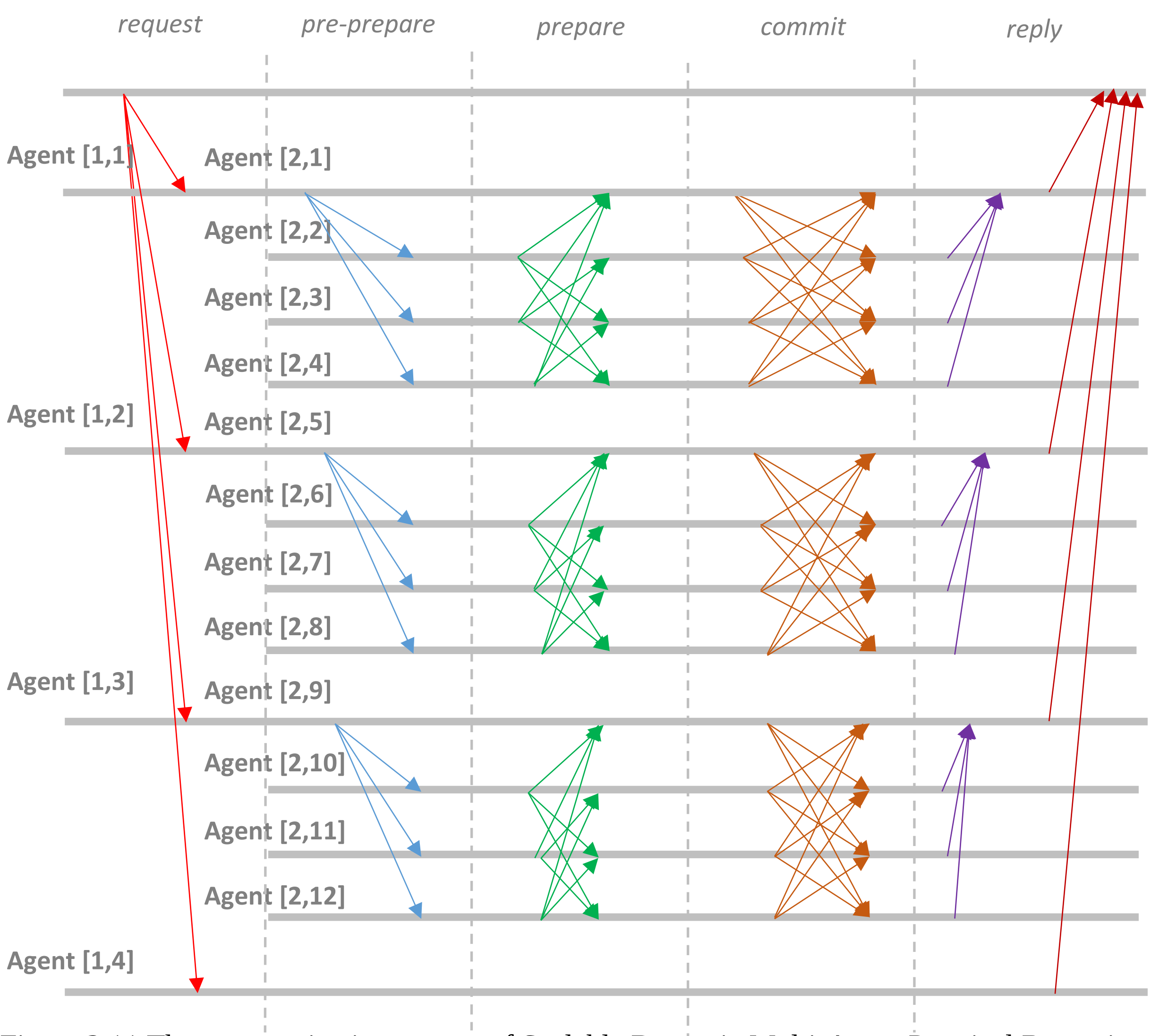


Figure 2.11 The communication pattern of Scalable Dynamic Multi-Agent Practical Byzantine Fault Tolerance (SDMA-PBFT) [6, Fig. 5]

2.9 Chapter Summary

Significantly, the structure of the pepper value chain is crucial to understand the relation and interactivity among stakeholders, as exhibited from neighboring countries' case studies. The case studies are important as there is currently no pepper value chain for Malaysia, therefore a reference point was necessitated. By referencing their value chains, Sarawak's pepper stakeholders were able to be partially identified and isolated some key areas for the selection of qualitative interview participants. Subsequently, pain points were identified and compared by using the weighting system, and also compared to pain points from the case studies for relevancy. In addition, the review on blockchain technology has shown its potentiality towards revolutionizing the agriculture industry, which enables the compatibility in fusing the two research subjects into a unified result.

CHAPTER 3: RESEARCH METHODOLOGY

This chapter details how data samples are acquired, mainly for determining pain points encountered by selected stakeholders in the pepper value chain in their daily operation and how they overcome challenges faced during volatile periods. In brief, qualitative interviews with snowball sampling technique were implemented to identify Sarawak's pepper value chain, simply the most suitable method in accessing hard-to-reach population [103].

3.1 Data Acquisition

The process of data collection is required to assess the current status of Sarawak's pepper value chain and determine the pain points encountered by stakeholders. Primary data sources comprised of these key stakeholders: smallholder farmers, collectors, processors, wholesalers, exporters, retailers, and end consumers, which are based on the general framework of an agricultural value chain. Structured interviews were conducted to collect primary data from stakeholders in the value chain. In some circumstances, interview questions were translated into native languages to facilitate communication. A minimum of three participants were interviewed for each stakeholder category in the value chain to understand the current structure of the pepper value chain residing in Sarawak. On the other hand, secondary data was collected via internet sources or websites such as the MPB, International Pepper Community (IPC), Department of Agriculture Sarawak (DoAS), and Department of Statistics Malaysia (DoSM). To get a better understanding prior to the sequence of structured interviews, Table 3.1 was created as a summarization towards the significance of stakeholders for each category, which the entirety is based on the literature review.

Table 3.1: A reviewed summarization for each stakeholder category

Category	**Characteristics/Responsibilities/Similarities**
Producer	Smallholder farmers are heavily depended by subsequent stakeholders, which gain dominance as the main producer instead of local private farms or under any foreign leaderships.
Collector	Mostly traverse with small transportation without concerning the quality of pepper berries or peppercorns. This group of individuals is significant because of the acquirement of pepper that require strenuous effort to arrive in sequestered locations.
Processor	Unsorted peppercorns received from the collectors will be sorted and processed by the processor. Sometimes, a trader (big collector) can also substitute to do pepper cleaning and grading with the compatible machinery.
Exporter	Exporters are highly sought out characters to maintain relationship with by the local traders and collectors as they can provide premium purchasing prices and punctual payment. More than half of the total

	production margin will consistently goes to the export company as domestic consumption is significantly less compared to the international demands.
Wholesaler	Wholesalers are considered the central hub of pepper procurement. To achieve a stable pepper supply, exporters will sign a long-term contract and will be prioritized with high-quality pepper catered to the international market. The remaining stocks will be distributed to the local retailers or end consumers that require in bulk.

3.2 Qualitative Snowballing

To determine and construct Sarawak's pepper value chain, a non-probability sampling technique was deployed, which is snowball sampling, also known as the chain-referral sampling. Out of all sampling techniques, snowball sampling is most suited for this study as the pepper value chain itself is interconnected with pepper stakeholders and with business relations towards each other. By utilizing the relations, the selected pepper stakeholders or participants were queried for future candidates that are related to the target characteristics or subsequent individuals that interconnect to each other within an undiscovered network [104]. For example, the primary subject provides the details of the second subject that is either within the same role, i.e., pepper farmers (horizontal linkage) or subsequent stakeholders (vertical linkage), and then moving on to the third subject, and so forth, until the retailer is reached. The question was asked in the following construct:

a) Where did you normally source the pepper crops? *Answer*
b) How did you manage to find the contact in the first place? *Answer*
c) Who is your frequent buyer? *Answer*
d) What role is the buyer partaking in the business? *Answer*
e) Any form of difficulties during the bargaining? *Answer*
f) What is your opinion about online business? *Answer*
g) Would you opt for digitalization as part of your current business operation? *Answer*

The above set of questions are part of the example and questions set in Appendix B. Using the questions set in Appendix B, uncertainties such as their previous and subsequent stakeholders were disclosed along with pain points when interacting among them. Moreover, their interest in participating digital transformation in Sarawak's pepper industry was illuminated based on the tone, expression, and response.

3.3 Research Framework

In Figure 3.1, preliminary studies including the identification of problem statement, formulation of objectives, and literature review were conducted to ascertain the attainment of the research project. Furthermore, a value chain was drafted to provide rough estimation on the roadmap for qualitative interviews. Qualitative data collection was done from the starting point of the value chain, which is the producer for the particular commodity; pepper. Data was collected based on two aspects: pain points and market linkages. A total of 32 respondents were scouted and being interviewed to achieve the data saturation, which can be reached when the maximum of three participants giving the similar response from the received questions. The researcher had several returns to the starting point of the value chain for the next trace upon reaching the finishing point. Concurrently, the researcher had interviewed several participants that situated have the same roles in the value chain and all data received was analyzed using thematic analysis, which is sufficient to identify common patterns when comparing transcripts, generate codes, and group relative codes into a theme. Finalized themes were then observed and numbered to create a percentage chart and determine the data saturation as the overall summary for the mid phase. Ultimately, Sarawak's pepper value chain was finalized by tracing the stakeholders using the snowball sampling and was relocated to the final phase, which is to digitalize the formulated value chain with integrated blockchain and consensus algorithm as its core mechanism.

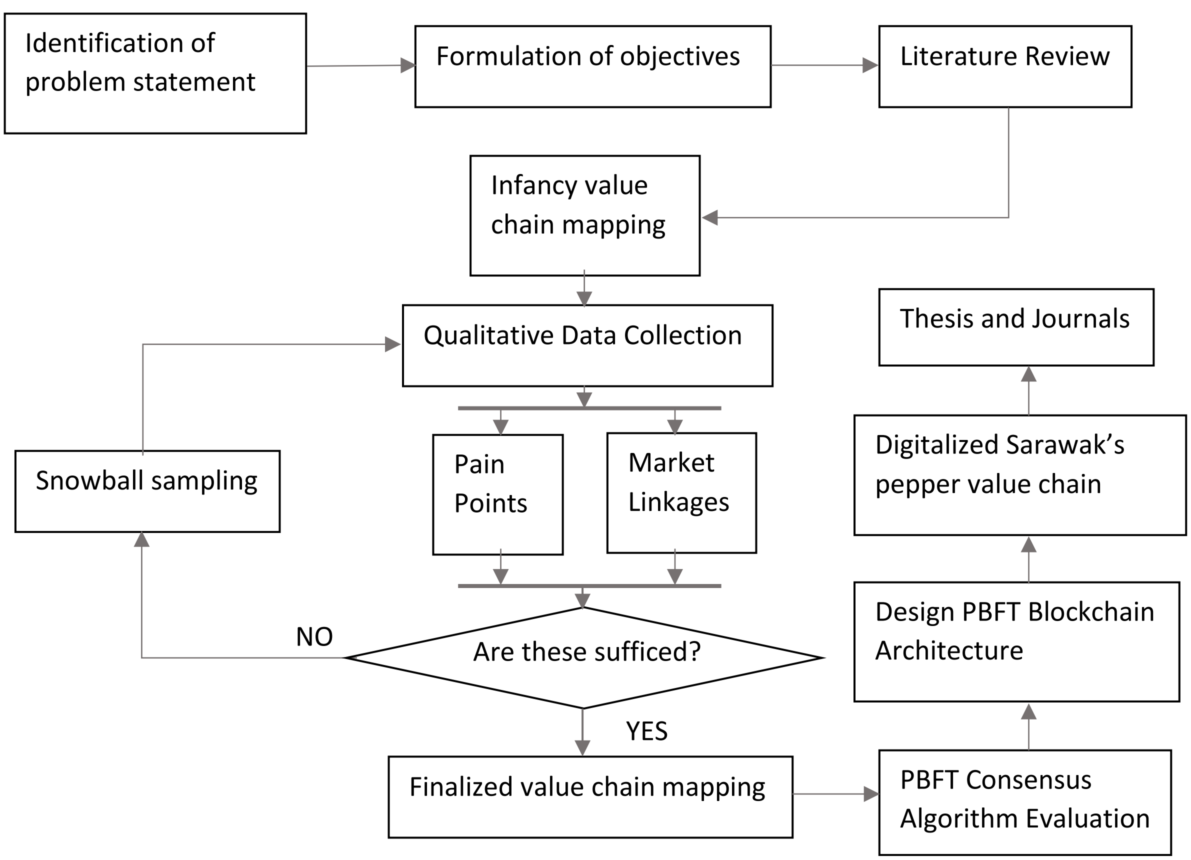


Figure 3.1 The systematic flowchart for the methodology research

In essence, the PBFT consensus algorithm were separated into three different network structures as test subjects. The test subjects were evaluated based on the performance, reliability, and scalability (PSR) metrics and compared by using line charts to manifest the final results and announce the most robust network structure. Subsequently, a proposed network structure and blockchain system architecture were drawn to represent the framework for the backbone of the software layer, in conjunction with the digitalized pepper value chain that connotes the interactivity between radio-frequency technologies (RFID & NFC) and the BCN. More technical aspects were described in the subchapter 5.1.

3.4 Ethical Consideration

The human ethics were approved by the Curtin International under the record number HRE2020-0413, and obtained via the InfoEd's e-Research Portal. Henceforward, the following ethical guidelines [105] were implemented during the qualitative interview:

a) Research participants should not be subjected to harm, either physically or emotionally.
b) Privacy of research participants are required to be kept confidential at all times.
c) Anonymity of research participants are ensured to protect their safety and reputation.

CHAPTER 4: RESULTS AND DISCUSSIONS ON QUALITATIVE INTERVIEWS

This chapter presents the notable findings of Sarawak's pepper industry and the final construct of the pepper value chain in Sarawak. Such findings are the characteristics and roles of the pepper stakeholders and the complete picture of Sarawak's pepper value chain with alternate marketing linkages. The linkages and pain points were listed according to each stakeholder category, starting from the producer to the end consumer. Finally, data analysis was done by computing the total weightage based on percentage agreement and comparing the discovered pain points from selected participants.

4.1 Demographic Profile of Respondents

A total of 32 respondents had contributed to the study of Sarawak's pepper value chain. The respondents are comprised of smallholder farmers, collectors, processors, exporters, wholesalers, retailers, customers, and supporters. Chosen participants are residents of in Miri, Sibuti, Sibu, Betong, Julau, and Kuching.

During the search phase, it is difficult to pinpoint a stakeholder that is only involved in the pepper business as majority of the smallholder farmers have followed the practice of multiple cropping; growing two or more crops at the same time, from cash crops like oil palms, durians, and coconuts to managing short-term vegetables. As for midstream and downstream actors in the value chain, the collected commodity is not restricted to only the pepper crop. Other commodities, such as ginger, garlic, and turmeric are being grinded into powder form, then packaged and marketed under their trading catalogues as spices. Hence, selected participants are mostly involved in diverse crops/spices and considered in this study. Although other commodities may raise similar pain points, this research is solely aim for pepper crops and the similarities shared to other commodities are not prioritized and may rely on the reader's point-of-view to justify its relation to the pain points encountered by the pepper stakeholders.

In brief, all information was verbally obtained through a set of compiled questions that is capable of revealing the characteristics and roles of the value chain actors, and was attached in the Appendix Section [Appendix B]. Subsequently, available findings were justified using thematic analysis; where common themes and patterns were categorized into groups and distributed into charts based on frequency of occurrence of the qualitative data from the interview transcripts [104].

Table 4.1: Demographic profile of pepper stakeholders

	Specification	**Respondents**	**Percentage (%)**
A.	**Age**		
i.	25-30 years	3	9.38
ii.	31-40 years	8	25
iii.	41-50 years	12	37.5
iv.	Above 50 years	9	28.12
	TOTAL:	**32**	**100**
B.	**Religion**		
i.	Christianity	15	46.87
ii.	Buddhism	11	34.38
iii.	Islam	2	6.25
iv.	Others	4	12.50
	TOTAL:	**32**	**100**
C.	**Experience**		
i.	Less than 5 years	12	37.5
ii.	5 - 10 years	15	46.87
iii.	11 – 15 years	3	9.38
iv.	15 years and above	2	6.25
	TOTAL:	**32**	**100**

In Table 4.1, there are 3 main specifications that helps to differentiate the demographic characteristics, which are based on their age, religion, and years of experience. For the first specification, the most received age group is situated within 41-50 years, followed by those from above 50 years and 31-40 years. The younger generation is counted as the least out of the total percentage as not many of this age group has ventured in pepper cultivation. For the second specification, the most encountered religion is Christianity, mostly from the indigenous tribes with a small portion coming from the Chinese race. Following the ranks will be Buddhism, Islam, and individuals that follow in native beliefs. For the third specification, the majority of the pepper stakeholders have less than 10 years of experience, with the veterans coming short, with just 5 individuals in total. Despite the low veteran count, the dominant experience groups are capable of supplying high-grade pepper products and more willing to allow digitalization as a form of modernizing their current business operation.

4.2 Characteristics and Roles of Sarawak's pepper value chain actors

4.2.1 Input Suppliers

For acquiring planting materials, MPB will normally advise smallholder farmers to purchase necessary fertilizers, pesticides, and weedicides from the appointed outlets as they have been inspected and consistently adhered to the regulations stapled by the policymaker [106]. Alternatively, pepper holders can also obtain planting materials from the statutory body through the nearest MPB premises.

4.2.2 Extension Agents

As is well known, MPB is also the extension agency for Sarawak's pepper sector. Customarily, MPB will provide regular assistance and advisory services to smallholder farmers who in dire need of succor regarding the calamity that happened in their pepper farms, i.e. the sudden curling leaves or recurrent bacterial leaf spot in several pepper vines. To prevent such circumstances from occurring, MPB agents may visit the holders' premises and examine the condition of the pepper plants by requests. On an annual basis, the Board will also conduct training courses with collaboration among research institutes for interested pepper holders to participate and gain knowledge of the techniques utilized in conventional farming practices [106]. As pepper is a labor-intensive cash crop, proper management of agricultural resources and land structure are not to be neglected. With the helping hand given by extension agents, smallholder farmers will learn the importance of achieving those criteria and adopt new farming technologies that can maximize the yearly yield of pepper berries.

4.2.3 Financial Agents

In Sarawak, microfinancing programmes are largely offered to agro-preneurs. Such sectors including pepper are being sighted as the importance of benefiting the state's economy. Among the financial sectors, Agrobank are considering as the powerhouse behind the aid initiatives. An example of the micro financing scheme called Agro Tegas has been provided to B40 income group and individuals that involved in agriculture entrepreneurship ventures. Furthermore, Agrobank also signed a Memorandum of Understanding (MoU) with the MPB for the purpose of benefiting 30,000 pepper smallholders and upscaling their socio economic status in Sarawak [107]. These commitments provided by Agrobank are prominent, thus landed a susceptible role in Sarawak's pepper value chain.

4.2.4 Agricultural Scientists and Researchers

In 1967, Agriculture Research Centre (ARC) was built in Semongok, Kuching to conduct crop research pertaining to the farming sector of Sarawak. Originally, it was established to investigate the epidemics of the Phytophthora foot rot that affected pepper holdings on their annual production. To date, agricultural scientists are regarded as the major footing for providing the disease-resistant pepper cultivars and newfound discoveries in increasing the success rate of fruit bearings and yearly yields of peppercorns to smallholder farmers and entrepreneurs. Agricultural scientists are also tasked to preserve the germplasm of the commercially valuable pepper species for the continuation of high-yield and good quality of pepper berries. At the time of writing, Semongok Aman, Emas, and Perak are the highly recommended cultivars found by the agricultural scientists in the local centre and introduced to local farmers, which can be seen cultivated in partial of their pepper garden along with the Kuching variety.

Additionally, agricultural scientists have been researching the versatile usages of pepper berries aside from being utilized as typical condiments. Oleoresin and oil from pepper are another by-product that can be applied as preservatives and ointments due to its medicinal properties. To extend that effort, the MPB had sign the Memorandum of Understanding (MoU) with academic institutions such as Curtin University of Technology Sarawak and University Putra Malaysia (UPM) [108]. These strategic partnerships among universities would help to boost commercialization on the local commodity by producing varieties of pepper nutraceutical products based on research outcomes from agricultural researchers in their respective research projects [109].

4.2.5 Nursery Operators

Besides being known as research institutes, Agriculture Research Station (ARC) and University Putra Malaysia (UPM) have built-in plant house specially for cultivating pepper plants. Smallholder farmers and fellow enthusiasts can procure pepper plants through stem cutting or unprocessed pepper berries with removed pericarp from the plant house. Hence, these locations are also known as the nursery operators that nurtured well-bred pepper stems and organic seeds via germplasm selection.

4.2.6 Smallholder Farmers

Relative to other actors in Sarawak's pepper value chain, smallholder farmers are most vulnerable. They have been vastly affected by the recent downward trend of market price for the commodity. According to one of the respondent, it is most unlikely to have pepper farmers depend solely on pepper cultivation and production since the market fluctuation of pepper is considerably high and volatile within recent years. In order to surmount the decline in pepper price, pepper farmers will have to rely on short-term crops and other relative cash crops such as bananas, coconuts, durians, and pineapples to maintain their pepper farms and also support their livelihood.

When comparing black and white pepper producers, farmers that solely produce black pepper are comparatively poorer and prone to sell the dried pepper berries immediately with no regards on the lower market pricing. Based on the yearly experience of several participants, they will normally sell the commodity right after the pre-processed stage, which includes the stem and extraneous matter separation by hand or motorized pepper thresher and first drying for reducing the moisture content and surface darkening. As for white pepper producers, they are more affluent and flexible in costing as they can purchase more expensive seedlings and fertilizers for growing and harvesting bigger pepper berries in return. Moreover, they are able to store the pre-processed pepper berries in their repositories when the market price is substantially low.

Amongst another respondent of the interview, the golden age of pepper commercialization has been indefinitely replaced by the oil palm industry as they can fetch in higher profits from commercial buyers and greater demand due to its versatile usage in range of daily products. The respondent also added that smallholder farmers are gradually abandoning pepper gardens because of high susceptibility of pests and diseases. Based on the yearly observation, a pepper garden can be destroyed within a few months' time when a disease outbreak occurs. One of the disease outbreaks is the Phytophthora root rot, which is caused by the over-dampening of underlying soil medium, eventually creating a conducive environment for the infection to grow on the underground stem. As indicated by the local agricultural department, the underground stem will progressively manifest into brownish-black lesion, signifying the perish state of the whole pepper vine with leaves gradually turning into yellowed and wilted [110]. Ineluctably, portion of smallholder farmers had decided to venture new businesses with minimal risks required to anticipate, instead of continuing their operations on the pepper gardens while others are implementing integrated farming as oppose to monoculture approaches for withstanding the above deficiency along with the price instability in the global pepper market.

4.2.7 Pepper Cutting Entrepreneurs

According to the MPB website, smallholder farmers are able to join an entrepreneur scheme, becoming a role entitled the Pepper Cutting Entrepreneur [111]. To become a Pepper Cutting Entrepreneur, participants are required to cultivate a minimum of 600 pepper vines from recommended varieties such as Semonggok Aman and Semonggok Emas on their current pepper farm with approximately 0.3 hectares and registered as an affiliate under the MPB [111]. Once participants meet the prerequisites, they will be given an additional 400 pepper cuttings and an assortment of fertilizers including organic fertilizers, Carbofuran, Benomyl, and Nitrogen-Phosphorus-Potassium (NPK), which are indispensable to ward off natural pests and diseases [111].

Besides, pepper cutting entrepreneurs will be provided with frequent hand-to-hand farming practices, site visits, and essential advices on becoming both successful farmer and entrepreneur. This intervention from the Board can encourage smallholder farmers to stay competitive in the international market and overcome short-term market fluctuations. The inculcation of entrepreneurship mindset among smallholder farmers may also allow them to create more innovative pepper products through their own series of value-adding activities. In Sarawak's pepper value chain, they are considered as large producers and have the ability to manage their own value-adding activities such as cleaning and packaging without relying much on chain intermediaries.

4.2.8 Foreign Investors

In order to maximize the total production of pepper, the act of joint venture with foreign investors is strongly encouraged as they have the competence in building a large-scale pepper farm. Large-scale pepper farms enabled Sarawak to realize mass production, eventually increase the amount of yearly yield on multiple folds. Potential investors can be sourced from countries such as Japan [112], China, South Korea, and Singapore as they are the major importers of Sarawak Pepper products and among the top pioneers in technology advancements [113]. This may also bring additional advantage for enabling the possibility of structuring a modernized pepper farm integrated with state-to-the-art sensors and actuators. This subtle approach can become a competitive advantage against other pepper producing countries. In Vietnam, huge production can be manifested due to the increasingly populated large-scale pepper plantations that started and operated by investors from India [114]. As for the current state, Sarawak has not been able to cultivate higher or equivalent amount of pepper crops compared to majority of pepper producing countries, which can be denoted as the weak point for the current local pepper industry since it mainly depends on smallholder farmers as the sole producer of pepper.

4.2.9 Village Collectors

Situated in rural territories, village collectors are also most commonly known as small traders that transport pepper in small quantities. Rural producers that did not possess any form of vehicle can only rely on these collectors to gather the commodity and sell to another stakeholder in the value chain. In the case of Julau, accessibility to the pepper farm has been posited a challenge due to uneven road surfaces, in addition to diverge pepper planters located in secluded, hilly areas. Hence, village collectors have always been assigned to scout commodities that are hardly reachable by average traders.

4.2.10 Town Traders

Another type of traders in Sarawak’s pepper value chain are known as town traders, akin to village collectors but able to gather and store pepper in larger quantities. Town traders may also rely on village collectors to scout more pepper farmers as some enclosed areas may be unknown and difficult to traverse.

4.2.11 Farmer’s Association

According to a news report, the farmer organization in Betong had being upgraded with installed pepper processing machine to enhance the efficiency of processing and packaging the harvested pepper berries [115]. Subsequently, the packaged products will be either sold or exported to interested countries. Hence, smallholder farmers will have the alternative marketing channel by selling their dried pepper berries to the farmer organization at a favorable selling price even when the global pepper economy is experiencing a continuous downturn [115]. Eventually, pepper farmers will be able to undergo farm maintenances and resupply input materials without having to abandon their pepper farms due to the lack of financial returns from the previous batches of harvested pepper berries.

4.2.12 Government Statutory Body

The body is represented by the MPB, which acts as the buyer and exporter in Sarawak's pepper value chain. The main objective for the establishment of MPB is to alleviate the discomfort of smallholder farmers that did not have the bargaining power against private merchants, which normally have to obey the offered price by the approaching buyers. Even when supply is higher than demand, MPB will still acquire the harvested pepper berries from smallholder farmers as they require immediate capital returns to continue operating and maintaining their pepper farms. Moreover, smallholder farmers will also unlikely to upkeep dried pepper berries in long duration because majority of them do not own a spacious warehouse or storage room in their premises. Fortunately, smallholder farmers are being offered a higher selling price by the government statutory body compared to the selling price provided by private traders. However, smallholder farmers will offload their commodities to private traders due to the long distance required to travel from their pepper farms to the nearest MPB collection point and the storage capacity offered by the MPB's warehouses may not be sufficient during the peak seasons.

Apart from partaking the buyer role, MPB is also responsible for supervising the overall production of pepper products with the implementation of utmost quality control and grading system and devising international marketing strategy. With the intervention from the Board, many citizens of countries such as Japan, South Korea, and Singapore are well-informed of the stringent quality of Sarawak's pepper via constant publicity campaigns and able to convince them to import the condiment into their nation for daily consumption. According to a representative, MPB commonly purchases pepper berries from these following stakeholders: smallholder farmers, village collectors, entrepreneurs, and farmer organizations. The purchasing of pepper berries is done in two methods: field purchase and spot purchase. The first method will require MPB agents to visit the premise of sellers and fulfil the transaction with instant cash whereas the second method is reversed, whereby sellers will transport their harvested pepper berries to the MPB's warehouses. Purchased pepper berries will then be sent to processing centres equipped with Mikrokleen machineries [116]. Mikrokleen machineries conduct steam treatment to enhance the aroma, flavor, and ensure hygiene of pepper.

4.2.13 Product Manufacturers and Processors

According to a factory overseer, pepper producers may begin the pre-processed stage before selling to subsequent buyers. Different colors of pepper: black and white are being processed differently. Black pepper will only require to be sun-dried until the outer skin becomes blackened whereas white pepper will need to be soaked or rinsed in flowing water beforehand. After the outer skin is removed, the white pepper will undergo the same drying process as the black pepper. Once peppercorns are dried completely, smallholder farmers will perform the sifting and threshing by hand or machine to eliminate extraneous matters prior to the packing of dried peppercorns in gunny sacks, then change hands to subsequent buyers such as village collectors, town traders, farmer associations, and MPB agents.

In most cases, another pepper processing stage will be associated before heading to commercial labelling and packaging, especially when the final product is bound to be exported to international customers that prioritized on Sarawak's finest quality. It is known as post-processed stage and comprised the following activities: cleaning, grading, and packaging. Although pepper berries have undergone rudimentary cleaning by the producers, excrements from animals or insects to pathogen may still contaminate the condiment and required to be sterilized in a microscopic level. The method used is called steam sterilization and mainly operated in private facilities or MPB processing centers.

4.2.14 International Exporters

In order to export pepper products worldwide, a company has to obtain the export license from the MPB and be registered as the member of Sarawak's Pepper Exporter Association (SPEA). According to the Assistant Director of MPB's Strategic Planning Division, pepper consignments are subjected to meticulous inspection by the Pepper Marketing Board (PMB) to certify all prepared condiments have been achieving the grade specifications as requested from international buyers before proceeding to shipping. In addition, pepper consignments are subsequently examined by the ISO accredited Quality Control Laboratories (QCL) to conduct the residue level analysis for pesticides and heavy metals and ensure all pepper condiments are safe for the later consumption [117]. All rejected consignments will either be undergone another round of inspection or retrocede to the particular exporter for repackaging. These series of inspection allow Sarawak's Pepper to be crowned as the finest quality of pepper among producing nations with "Hallmark of Quality" as the daily promotion trademark and registered as one of the indigenous Geographical Indication (GI) in Malaysia [118].

4.2.15 Wholesalers and Retailers

In every supply chain, wholesalers and retailers are the fundamental blocks for supplying packaged products to domestic consumers. Consumers can opt for buying pepper products in small quantity from the nearest retailer or in bulk from a wholesaler, which can be purchased in a much cheaper price based on the wholesale pricing instead of the retail pricing.

4.2.16 Digital Entrepreneurs

With the ever-expanding competition among wholesalers and retailers, online business has been targeted as another marketing option by creating a digitally, visible storefront for sorts of commodities [119]. Those who are technological literate would publish catalogues of pepper packaging products to the online marketplace or their own hosted e-commerce websites as an alternative strategy in reaching out remote customers, either domestically or internationally.

Table 4.2: A checklist of primary and supporting actors

Actors	Primary		Supporting
Input suppliers			✓
Extension agents			✓
Financial agent			✓
Agricultural scientists and researchers			✓
Nursery operators			✓
Smallholder farmers	✓		
Pepper Cutting Entrepreneurs	✓		
Foreign investors	✓		
Village collectors	✓		
Town traders	✓		
Farmer's Association			✓
Government Statutory Body			✓
Product manufacturers and processors	✓		
International exporters	✓		
Wholesalers	✓		
Retailers	✓		

In short, a total of 16 different characters were described, or to be specific, 10 primary actors: smallholder farmers, Pepper Cutting entrepreneurs, collectors, investors, traders, processors, product manufacturers, exporters, wholesalers, and retailers, along with 6 supporting actors: input suppliers, financial agents, research institutes, nursery operators, extension agents, government statutory body, and the farmer's association. During the actual interviews, not all of the characters were chosen, with some such as MPB to only receive two recipients due to the single source that can disregard the requirement of data saturation and limitations in finding the suitable participant. To further clarify, the primary actors are stakeholders that directly contribute, process, and manage the pepper in any form whereas the supporting actors are stakeholders that assist primary actors with assorted services. Additional information pertaining to their interactivities will be described in the next subchapter.

4.3 Design Structure of Sarawak's pepper value chain

Figure 4.1 shows the overall structure of Sarawak's pepper value chain with associated stakeholders or actors as verified through the qualitative interview process. Firstly, raw materials and resources are supplied by the input suppliers, finance officers, research center, and nursey operators, excluding the agricultural extension agents, which are mainly providing technical expertise and advisory services to the existing producers: smallholder farmers and local entrepreneurs. Secondly, trading and processing services are provided by the collectors-processors, traders-processors, farmer organizations, and hugely assisted by the MPB. Lastly, the tailpiece of the value chain is predominantly acquired by wholesalers and exporters, which are tasked for packaging and distributing final products to the subsequent stakeholders in bulk, either domestically or internationally.

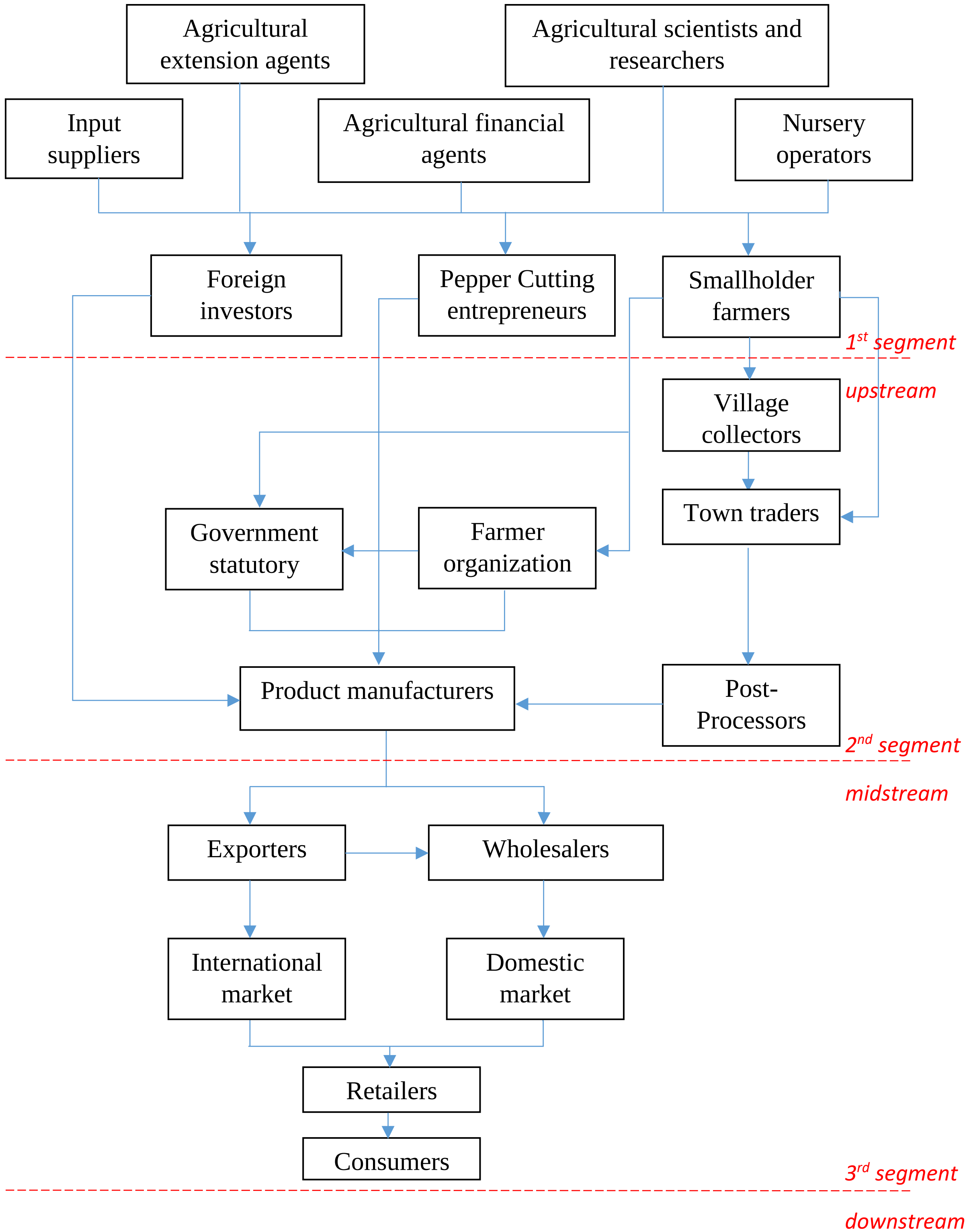


Figure 4.1 The conform Sarawak's pepper value chain

Separately, the structure of Sarawak's pepper value chain and the identified marketing linkages between the value chain actors are as shown in Table 4.3.

Table 4.3: Various marketing linkages of pepper value chain

a.	Smallholder farmers -> Government statutory body -> Product manufacturers -> Wholesalers / Exporters -> Retailers -> Consumers
b.	Smallholder farmers -> Village collectors -> Town traders -> Post-processors -> Product manufacturers -> Wholesalers / Exporters -> Retailers -> Consumers
c.	Smallholder farmers -> Town Traders -> Post-processors -> Product manufacturers -> Wholesalers / Exporters -> Retailers -> Consumers
d.	Smallholder farmers -> Farmer organization-> Government statutory body -> Product manufacturers -> Wholesalers / Exporters -> Retailers -> Consumers
e.	Pepper cutting entrepreneurs -> Government statutory body -> Product manufacturers -> Wholesalers / Exporters -> Retailers -> Consumers
f.	Pepper cutting entrepreneurs -> Product manufacturers -> Wholesalers / Exporters -> Retailers -> Consumers
g.	Foreign investor-> Product manufacturers -> Wholesalers / Exporters -> Retailers -> Consumers

Currently, there are a total of 7 marketing linkages branched out from the 3 producers. Smallholder farmers are having 4 major buyers, which are the collectors, traders, government statutory body, and farmer organization. Despite the available channels, most smallholder farmers are more leaning towards the government as their main potential buyer due to the premium purchasing prices offered by the MPB. Secondly, pepper cutting entrepreneurs are having 2 options: self-processed or MPB-processed. Self-processed can be accomplished by transporting the pepper crops to the processor or having the processing machines themselves. Those who relies on MPB will be undergoing the same process as smallholder farmers, waiting for the pickup or transport to the nearest MPB branch with their owned transports. Lastly, foreign investors will have their own factory or another third-party processing companies to process the harvested pepper crops, thus explain the solely marketing channel.

In Figure 4.2, the average of subsequent pricing is also conformed from pepper stakeholders in different stages, starting from the farm-gate price of the pepper producer. From MPB, the purchasing price will always be higher than normal traders to assist smallholder farmers that could not bargain for slightly higher prices, especially during economy downturn, which may affect their reproduction line in the upcoming seasons. As for processing, there are two distinct product outcomes: regular and Mikroleen. At the time of the interview, which is between the month of June and November in year 2020, regular is categorized with grades and marked within the price range of RM20 to RM40 per kilogram whereas the Mikroleen will undergo steam treatment activities to eliminate tiny extraneous entities, mostly prioritized for foreign markets that able to fetch higher prices due to its ascertain quality standard and acknowledged by adepts in culinary arts. According to an interview with a veteran, smallholder farmers and collectors would mostly opt for MPB, then from MPB to regular processing, in conjunction with the demand for regular processing is invariably higher, thus making it the most common route in Sarawak's pepper value chain. This price variation simply draws out different linkages coming from a single source to multiple buyers; commonly opt for MPB by majority of the smallholder farmers and to traders as the alternative route in the trading phase while the processing phase can be a mixture of both markets: domestic and international, which primarily depends on the level of quality necessitated by the subsequent buyers.

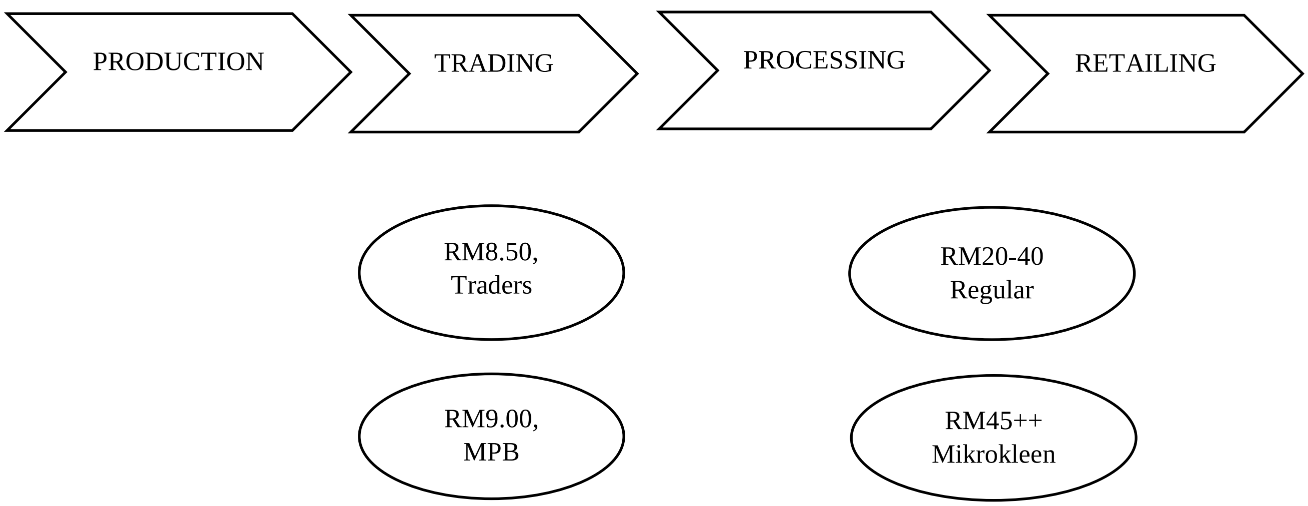


Figure 4.2 Price of the pepper crops (black variant per kg) in pre- and post-processing

4.4 Pain Points of Sarawak's pepper value chain actors

Pain points in a value chain are basically constraints that need to overcome by value chain stakeholders to prevent large and costly effects to upstream and downstream activities, also known as the bullwhip effect. Certain examples would be the untraceable of product whereabouts, the absence of consensus scorecards, and the lack of value-adding activities that are required to satisfy demands from end-users. In this section, pain points were properly scouted from domestic articles, newsletters, and interview transcripts received among selected stakeholders, summarized, and charted as below.

4.4.1 Smallholder Farmers

Interview transcripts were acquired from a total of six smallholder farmers. A total of nineteen constraints/themes transpired from the interview transcripts of the six smallholder farmers, as shown in Table 4.4. The constraints were weighted based on percentage agreement by the respondents. Where a constraint is highly agreed among the respondent, it would carry a higher weightage, and where a constraint was only agreed by a small number of the respondents, it would have a lower weightage. This then highlights the major constraints faced by the stakeholders. For instance, the constraint "increasing of agricultural inputs" from Table 4.4 has 6 participants agreed, therefore with a total response of 44, including the response from main and other constraints, would be (6 / 44) * 100 ≈ 14. A standard formula is shown as Equation (4.1).

$$weightage = \frac{total\ reponse\ for\ a\ constraint}{total\ response\ for\ all\ constraints} x\ 100 \qquad (4.1)$$

In Figure 4.3, the most severe constraints identified by all the respondents in this category is the increasing cost of agricultural inputs, and price fluctuations, occupying a 14% weightage respectively, compared to the other constraints. Financially, smallholder farmers are not in a favorable condition due to the increasing cost of agricultural inputs to provide fundamental elements for plant growth: nitrogen (N), phosphorus (P), and potassium (K). The deficiency of the above nutrients will eventually weaken the quality of pepper crops and increase its vulnerability to prominent pest and diseases. Another significant constraint is the low bargaining power against buyer, as agreed upon by five of the respondents. Four of the respondents mentioned as a constraint, the escalating cost for countering pest and disease, which includes the recovery cost of restoring the aftermath by the infestation of bugs and diseases that can be widespread through the field of pepper vines. Ineffective fertilizers provided and subsidized by MPB was also mentioned as a constraint by four of the respondents. Although input materials are given and subsidized annually by the MPB, the effectiveness of growth enhancements for pepper crops is not as high as expected and this resulted in farmers having to purchase externally from stores familiar to them.

As they are situated in the rural areas, several smallholder farmers are having difficulties in migrating to the digital era because of limited internet coverage, inaccessibility to innovation, farming technologies, and credits. Being connected through the internet can allow them to broaden their marketing channels and access to digital services. Such services could be credits accessibility and daily operation enquiries from financial institutions and MPB extension agents. Due to the lack of branch facilities, smallholder farmers will have to travel a considerable distance before arriving at collection centers, for instance, a distance of approximately 50km from Julau to the Sarikei MPB branch. The long-distance travel indicated the inconveniences rural stakeholders have to face, in addition to increasingly eroded or poor road infrastructures due to lack of maintenance.

As the constraints persist, many smallholder farmers have decided to abandon their daily operation by abandoning pepper farms either to cultivate or maintain other cash crops such as oil palms and durians or anticipate new business ventures with no relation to the agricultural sector. Furthermore, three of the respondents concurred on the lack of vehicle transport, inadequate extension services, heavy rainfall, lack of storage facilities, and limited internet coverage, inaccessibility to innovation, farming technologies, and credits. Lastly, two of the respondents mentioned as a main constraint, the lack of interest from new generations on continuing the pepper business since it requires them to invest a substantial amount of effort to maintain the pepper vines in a favorable condition, e.g., regular leaf pruning, fertilizing, and maintain ground covering.

Table 4.4: Constraints faced by smallholder farmers

<table>
<tr><th>Main constraints</th><th>Weightage based on % agreement by respondents</th></tr>
<tr><td>Increasing cost of agricultural inputs</td><td>14</td></tr>
<tr><td>Price fluctuation</td><td>14</td></tr>
<tr><td>Low bargaining power against buyers</td><td>11</td></tr>
<tr><td>Heavy rainfall that intensify river flooding</td><td>11</td></tr>
<tr><td>Escalating cost for countering pest and disease</td><td>9</td></tr>
<tr><td>Ineffective fertilizers provided and subsidized by MPB</td><td>9</td></tr>
<tr><td>Lack of vehicle transport</td><td>7</td></tr>
<tr><td>Inadequate extension services</td><td>7</td></tr>
<tr><td>Lack of storage facilities</td><td>7</td></tr>
<tr><td>Poor interest from newly generations</td><td>4</td></tr>
<tr><td>Other constraints</td><td></td></tr>
<tr><td>Unable to sell available harvests to MPB due to overstocked during peak season</td><td rowspan="9">7</td></tr>
<tr><td>Lack of entrepreneurship skills</td></tr>
<tr><td>Inaccessibility to innovation and farming technologies</td></tr>
<tr><td>Availability of credits for farm maintenance and operation</td></tr>
<tr><td>Persistence on traditional planting methods</td></tr>
<tr><td>Poor land, irrigation, and soil fertility management</td></tr>
<tr><td>Long distance to the central market</td></tr>
<tr><td>Little knowledge pertaining to post-processing techniques</td></tr>
<tr><td>Little to no linkage between further end of the value chain</td></tr>
</table>

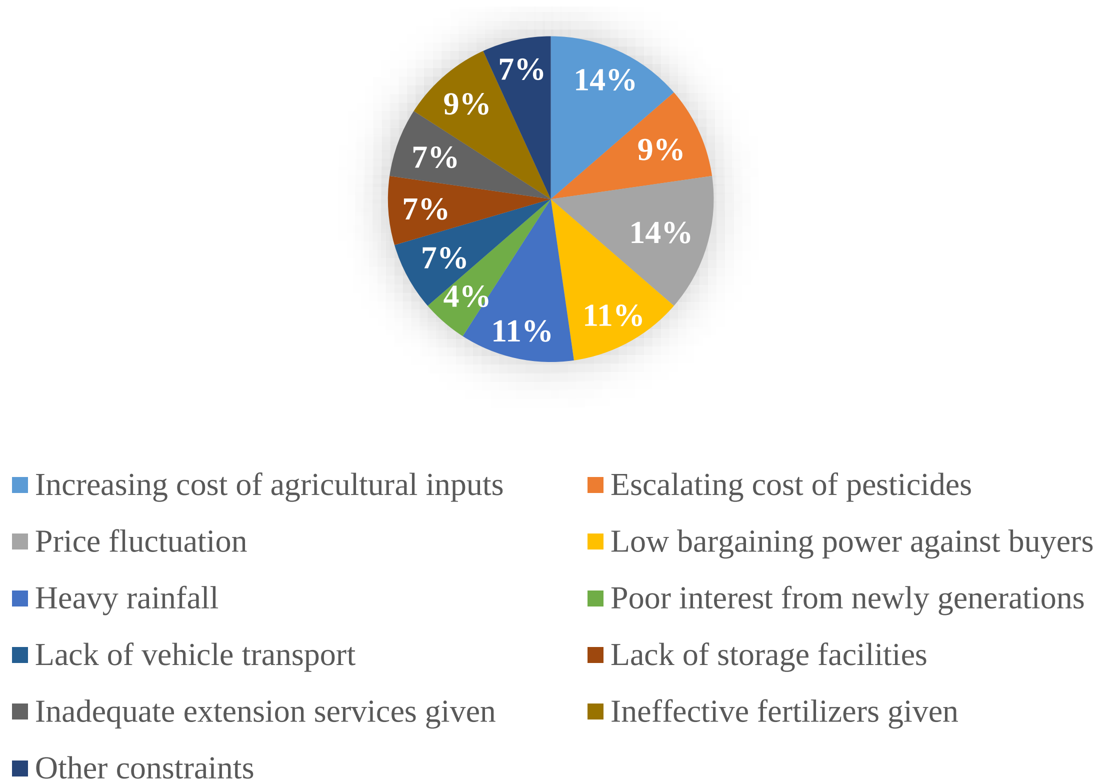


Figure 4.3 Percentage of smallholder farmers concurred on pain points

4.4.2 Village Collectors and Town Traders

The constraints faced by stakeholders in this category were acquired from a total of four respondents; two village collectors and two town traders. A total of nine constraints/themes transpired from the interview transcripts from two village collectors and two town traders, as shown in Table 4.5. In Figure 4.4, all of the respondents in this category agreed that improper road infrastructure, price fluctuation, mutual competition, and season-dependency are the most severe constraints, which occupied a 14% weightage compared to all other constraints. Three of the respondents also highlighted the fragmentation of supply source, improper storage assignment, and uncertain quality upon receiving the pepper crops from smallholder farmers as significant constraints. In many instances, collectors and traders will have to travel to multiple destinations and gather pepper crops from smallholder farmers. The supply source is considered fragmented, and when transacted in small quantities per area, it may not be worthwhile, according to three respondents in this category. Moreover, quality of the crop may not be as high as expected, which results in a lower purchase price offered, thus creating a knock-on effect on other smallholder farmers. In addition, collectors and traders will also compete among themselves and also against MPB because of the high buying price offered by MPB to the pepper producers. Whoever offers the best buying price will eventually gain the attention of smallholder farmers.

Table 4.5: Constraints faced by village collectors and town traders

Main constraints	Weightage based on % agreement by respondents
Improper road infrastructure	14
Price fluctuation	14
Competition from fellow collectors, traders, and MPB agents	14
Depends on harvest seasons	14
Fragmentation of supply source	11
Improper storage of collected pepper	11
Quality received is not as expected	11
Transact in small quantities for village collectors per trip	7
Low pepper productivity in certain districts	4

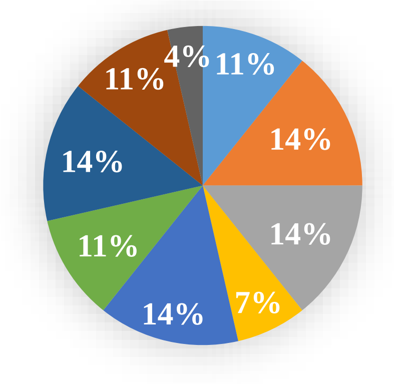


Figure 4.4 Percentage of village collectors and town traders concurred on pain points

4.4.3 Product Manufacturers and Processors

A total of five constraints/themes transpired from the interview transcripts of four respondents; two product manufacturers, one MPB processor, and one local processor, as shown in Table 4.6. In Figure 4.5, all of the respondents in this category concurred that price fluctuation, as well as high maintenance and labor cost, are the most severe constraints, contributing respectively to a 25% weightage compared to other constraints. It is worth-mentioning that labor cost also includes the difficulty in finding potential workers to alleviate the workload. Additionally, three of the respondents; two processors and one manufacturer commented that there is a reduction in quality when fine and inferior peppercorns are mixed together during the trade settlement. In managing post-processing activities, difficulties arise from having both fine and inferior quality peppercorns mixed together as it increases the workload of having to separate them into their respective grades. Consequently, labor requirement also increases, which is directly proportional to the expense paid per employee, as mentioned by all four respondents in this category. Another expense required is the regular maintenance cost for processing machines; as well as for Mikrokleen machines that operate for steam treatment of peppercorns. Moreover, reduction in quality is inevitable when passing through multiple actors in the value chain as there is a lag time between when the pepper berries are freshly picked, to the time it was processed. Another constraint mentioned by two of the respondents in this category is the lack of creativity in producing innovative value-added products to create more versatilities using local commodities. A wide selection of pepper products can boost commercialization and usage of locally harvested pepper berries. Hence, the cyclical nature of the pepper sector will be more affluent with a greater number of stakeholders, especially the producers.

Table 4.6: Constraints faced by product manufacturers and processors

Main constraints	**Weightage based on % agreement by respondents**
Price fluctuation; bullwhip effect based on consumer demand	25
High maintenance and labor cost	25
Reduction in quality when passing several hands in the value chain	19
Mixture between fine and inferior peppercorns	19
Lack of innovation for producing value-added products	12

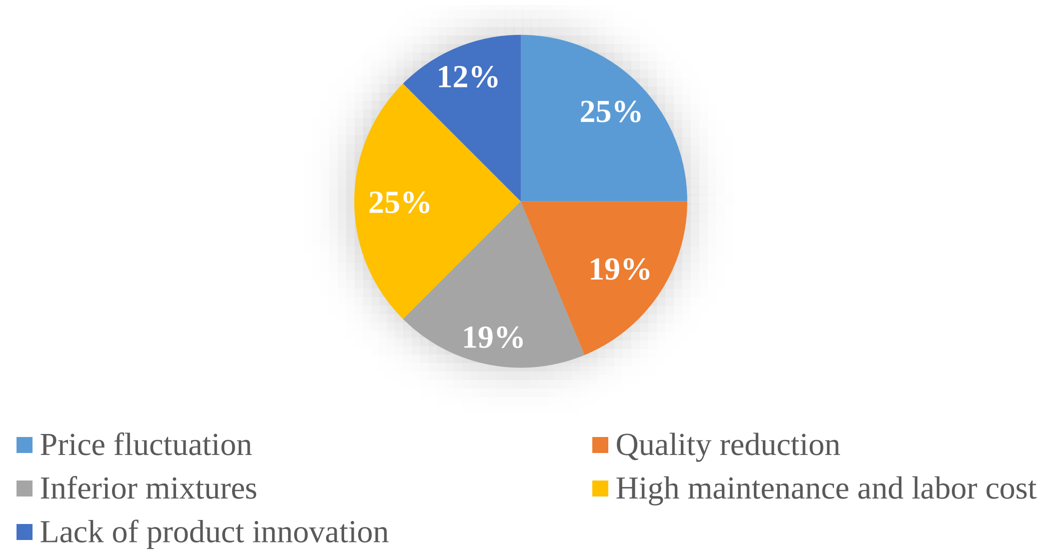


Figure 4.5 Percentage of product manufacturers and processors concurred on pain points

4.4.4 Wholesalers and Retailers

Constraints faced by wholesalers and retailers were acquired from a total of five respondents in this category. A total of four constraints/themes transpired from the interview transcripts of three wholesalers and two retailers, as shown in Table 4.7. In Figure 4.6, mutual competition in the pepper business was identified as the most severe constraint for wholesalers and retailers, resulting in a 33% weightage compared to the other constraints. Impacted by competitive pressure, they turned to alternative selling options, such as e-commerce platform, and through social media. Four of the respondents affirmed that the price fluctuation as well as the lack of demand and consumption in domestic markets as major constraints. Two retailers also mentioned as a constraint, the lack of understanding pertaining to the harvesting and processing phase, which posed a potential issue upon describing the authenticity of the pepper products to interested customers. The product integrity is unbeknownst to most of the subsequent stakeholders in the value chain, resulting in reduced buyer confidence from end consumers and create a lack of demand in the commercial market.

Table 4.7: Constraints faced by wholesalers and retailers

Main constraints	**Weightage based on % agreement by respondents**
Competition from fellow wholesalers and retailers	33
Fluctuating local market prices	27
Low consumption in domestic markets	27
Lack of understanding pertaining to behind-the-scenes operation	13

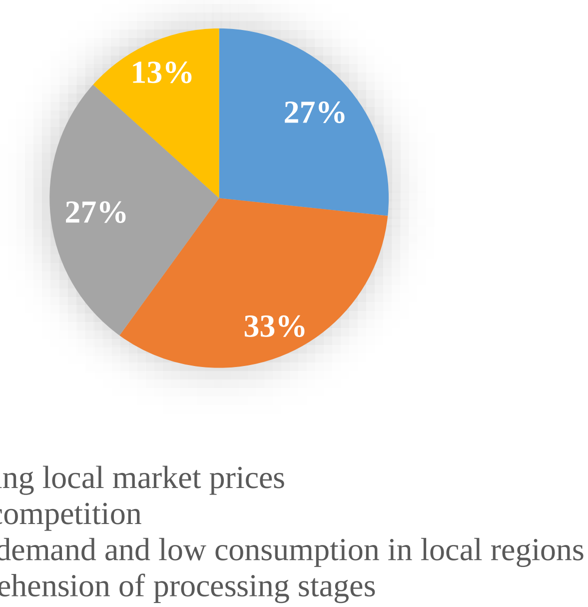


Figure 4.6 Percentage of wholesalers and retailers concurred on pain points

4.4.5 Exporters

Constraints faced by exporters were acquired from a total of three respondents in this category. A total of five constraints/themes transpired from the interview transcripts of two domestic exporters and one international exporter, as shown in Table 4.8. In Figure 4.7, all of the respondents agreed that the fluctuating international markets, mutual competition among exporters, and the repercussions of rejected pepper products before the consignment, are major constraints faced by them as indicated by 25% respective weightage as compared to other constraints. Moreover, two of the respondents highlighted that different quality standards across different countries also affected the pepper trading industry.

Sarawak's peppercorns are being acknowledged as the world's finest, thus many import countries have high expectations of the quality of Sarawak's peppercorns and demand that it meets stringent standards. Inevitably, exporters will have to adhere to those standards in compliance with the regulation and trade policy issued by the MPB. Each consignment will undergo thorough quality inspections before proceeding to international dispatch. Any rejected consignments will be delivered back to the corresponding exporters as a repercussion. Lastly, one of the respondent is concerned about the absence of a close link with the upstream stakeholders in the pepper value chain; in particular, the pepper producers. Since there is no direct communication to upstream stakeholders in the value chain, exporters are unable to pinpoint the source of any inferior quality pepper distributed along the supply chain.

Table 4.8: Constraints faced by domestic and international exporters

Main constraints	**Weightage based on % agreement by respondents**
Fluctuating export market prices	23
Competition from fellow domestic and international exporters	23
Repercussion of rejected pepper products after quality inspection	23
Quality standards from different countries may inhibit successful trading	16
Absence of close relation to stakeholders resided in the earlier nodes of the value chain	15

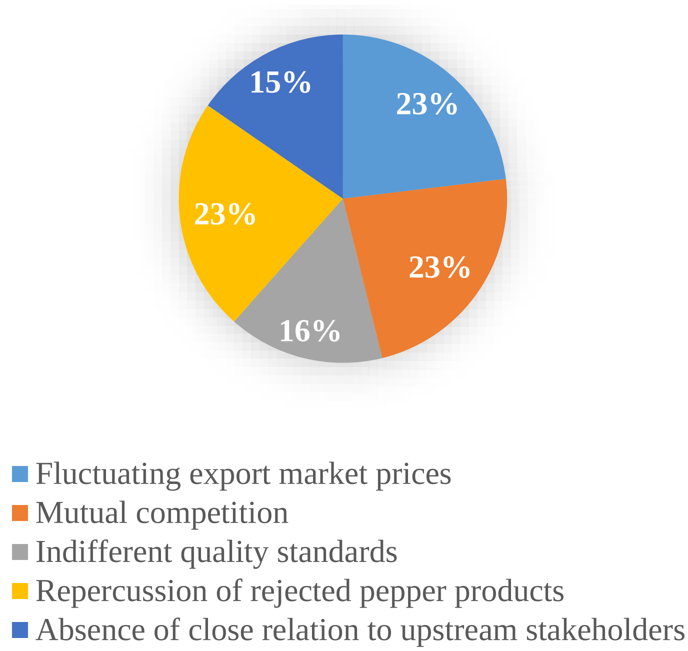


Figure 4.7 Percentage of domestic and international exporters concurred on pain points

4.4.6 Supporters

In this context, supporters can be defined as stakeholders that offer necessitated services to the primary actors, especially towards smallholder farmers. According to the inputs from two participants, MPB is the main buyer, supporter, and supervisor among registered pepper stakeholders. Other supporters including bank institutions, agricultural research center (ARC), and input suppliers are also existed to provide the essential services and assistances required among smallholder farmers. However, there are some persistent issues that hinder the overall efficiency of the pepper sector, which is required to be addressed by the government statutory body, as continuously stated by the participants. One of the discovered constraints is the lack of transparency of the commodity flow. For example, it is uncertain whether the pepper commodity has been swapped with other foreign bred that does not have the stringent quality as regulated by the MPB.

When questioning the participants regarding the integrity of pepper products, it is hardly enough to trace back to the origin without having the proper catalogue of selling items in a database server. Among the local community, several had claimed that the purchased pepper products from commercial shelves are in fact not genuine, which suspected the mixture of counterfeit pepper imported from other producing countries. As a result, the everlasting reputation for being the renowned pepper producing country may come to a halt and be replaced indefinitely. Presently, Sarawak's pepper industry does not have an integrated and communication platform for performing digital services, in addition to the lack of data digitalization pertaining to the identification of pepper stakeholders and transaction archives.

During the harvest season, smallholder farmers are facing the bottleneck of selling out dried peppercorns due to the limited warehouse capacity offered by the MPB, thus the delay of financial return for small-scale producers. The deadlock in purchasing pepper from producers is transpired due to mass production from neighboring countries, i.e., Vietnam, India, and Indonesia with certain countries such as China attempting to build their own pepper farms for domestic consumption and thus reducing the reliance on importing pepper products. Furthermore, the lack of finance outreach to the rural communities is proven to be affecting the production efficiency of smallholder farmers as they could not afford to undergo farm maintenance and purchasing agricultural inputs for the cultivation of high-grade pepper crops [112].

Aside from financial support, MPB also provides extension services to smallholder farmers that relates to the knowledge of utilizing good agricultural practices (GAP) to the pepper farm. With the joint collaboration from agriculture research center (ARC) and local universities, extension agents have been regularly informed regarding the research findings from the latest experiment, then present those major discoveries during the annual convention or visitation of pepper farms from requested producers. Despite the continuous effort, there are pepper farmers that insisted on using traditional methods in farming management, which creates hindrances to sustainable production for the local pepper sector.

Constraints faced by supporters:

i. unable to create sustainable production for the pepper sector due to persistence from farmers using traditional planting methods
ii. absence of communication channel to every stakeholder in the pepper value chain
iii. lack of data digitalization for member records and archives
iv. lack of overall transparency and supervision in the pepper value chain
v. lack of finance outreach
vi. deadlock in purchasing pepper from producers due to mass production from other producing countries, resultantly overstocked in warehouses
vii. limited storage capacity during harvest seasons
viii. major competition from other pepper producing countries
ix. time taken and distance travelled to the producer’s premises that requested for extension services

4.4.7 Consumers

As sourced from a total of eight participants, consumers are the main influence in determining the sales rate of a pepper product. Such purchase decision is concluded based on these two factors: quality and price. However, buyers are unable to identify the authenticity and fairness of the product due to the lack of labelling and description stated. Additionally, there are currently a multitude of dubious brands with questionable values to choose from across the commercial shelves, which may confuse buyers to select the right product among the bunch. Although brands are diversified, the product itself is not versatile enough to boost domestic and international commercialization, eventually inhibits the incessant flow of the supply chain for pepper commodity.

Constraints faced by consumers:

i. unknown to product integrity and development such as the source of origin and manufacturing process
ii. multitude branding
iii. lack of product diversification

4.5 Discussions

This subchapter describes how collected results were apposite and relatable to the existing agricultural and pepper value chains. Furthermore, a result comparison between the local and foreign pepper value chains was made to gain new perspectives on pepper stakeholders' solidarity and dependability towards each other.

4.5.1 Smallholder Farmers

Local research shows that smallholder farmers are the individuals that manage to realize the mass production of pepper crops across nations, as also mentioned in case studies of Vietnam [29], Cambodia [32], and Sri Lanka [31]. On average between nations, 95% of the total pepper production comes from this stakeholder category, with private farm and estate owners enveloped the remaining portion of the shares [29] - [31]. Despite the dominance, smallholder farmers are still having low bargaining power and oftentimes sell off the crops without referring to the standard pricing. However, according to an interview with a staff from the MPB, pepper price for both variants: black and white, will be uploaded daily in their website or can be received by sending a SMS request, which is primarily for pepper stakeholders that are only accessible to 2G network (GMS). Although benefitting, it still depends on whether smallholder farmers will follow the price chart when negotiate with a third-party buyer. Similar to Vietnam, those who are considered affluent will store harvested pepper berries during bad market fluctuations, and clear repositories when the supply is scarce with a high profit margin [29]. In terms of demand, Vietnam has been disrupting the international pepper market with a massive supply of pepper. Based on Table 2.1 and 2.2, the total production and export of pepper were approximately 10-12 times higher compared to Malaysia and Sri Lanka. One of the main causes is the pepper production from Cambodia is mostly prioritized to the Vietnamese collectors, which resultantly contributed the sheer amount of the total pepper production and export in Vietnam [32]. Another cause is due to the leniency from both government parties; with Vietnam having unlimited expansion on pepper plantation [120], [121] whilst Cambodia having little assistance in promoting domestic sales, especially to the local exporters and without enforcing the policy of illegal pepper trading [32].

4.5.2 Village Collectors and Town Traders

According to the local study, village collectors and town traders have their own dissimilarities; with a village collector as the small carriage that frequently travel in treacherous routes whereas a town trader as the big carriage that typically roams on asphalt roads, which are proven to be ordinary when referring the information to the case studies. In Vietnam and India, collectors are riding motorbikes to fetch pepper in small quantities [29], [33]. The advantage of using small transports is due to the fact the challenging areas that need to venture by collectors in order to reach the destination. The scenario becomes exacerbate when smallholder farmers are segregated in different pepper farms, whereby the collectors will have to travel secluded paths on multiple turns, which reflects back to the case of Julau in Sarawak. Mutually, collectors and traders in different countries are facing similar competitions against each other, which was revealed as one of the highest weightage by respondents in Sarawak.

4.5.3 Product Manufacturers and Processors

In Sarawak, processing machineries are built in various MPB branches, farmer organizations, research institutes, and third-party processors with strong emphasis on grading and stringent standards. However, countries such as Cambodia and Sri Lanka are not facilitated with a sufficient amount of processing factories [31], [32]. In India, there are no grades and standards to ensure the high-quality of processed pepper and the differentiation is not fully incentivized [33]. Surprisingly, traders in Vietnam are totally replacing processors by partaking cleaning and grading with appropriate measures and fulfilling requirements solicited by the buyers [29]. Therefore, based on the context alone, Sarawak and Vietnam are hugely pivoted on the stringent quality standards and emphasized on food safety practices compared to the other nations.

4.5.4 Exporters

Similarly, both local study and case studies emphasize on price fluctuation as one of their main constraints, in conjunction with the price competition that have to encounter, either domestically and internationally. In Sarawak, quality is also posed to be the hindrance on successful trading if not taken care properly, which is also mentioned in the case study of Sri Lanka's pepper value chain, quoted low standards of pepper can cause inadequate supply and act as a trade barrier to international buyers [31]. In Sri Lanka's case study, it is also mentioned that the inadequate testing capabilities of local laboratories to meet the standard requirements and the lack of market research at international level are the causes of this repercussion, in addition to India's case study, quoted the lack of awareness about required quality for the exported produce among the early pepper stakeholders that may cause the same repercussion [31], [33]. Subsequently, the lack of proper information and dissemination of the producers and lack of control over production are also stated as Indian exporters' limitations in producing the intended qualities, which share the same meaning as the absence of close relation to the early stakeholders in Sarawak [33]. Hence, the main constraints found in the local study are considered relatable and justifiable after comparing to the case studies of neighboring countries.

4.5.5 Supporters

Based on the local results, the supporter role in Malaysia is pretty much dominated by the MPB, which is also the extension agents, a part of the research institutes, and the main buyer for the smallholder farmers and collectors. Conversely, pepper sector in Cambodia is not prioritized by its government, which lacks the unified body to regulate the pepper production, in addition to the lack of R&D strategy with limited market research and extension services [32], likewise the lack of formal institutions to support the pepper sector in India [33]. Additionally, the probe of concern into data availability for decision-making from India is also specified by the MPB, which are the lack data digitalization pertaining to the member records and the overall transparency of Sarawak's pepper value chain. Besides, the lack of finance outreach is also highlighted as an issue in Cambodia, Sarawak, and Sri Lanka [31], [32]. Overall, the establishment of MPB is proven to be favorable for Sarawak's pepper industry and has been assisted pepper stakeholders in processing and marketing, which is absent in mentioned countries thus far.

4.6 Chapter Summary

To sum up, qualitative interviews were conducted and brought to fruition, which all information was compiled into several themes and had achieved the desired objective, that is to identify Sarawak's pepper value chain by determining stakeholders' pain points and linkages. The findings are significant to provide a rationale and motivation to the next chapter. In the next chapter, the PBFT consensus algorithm is reviewed and evaluated with 3 network structures as the experimental subjects. Furthermore, the chosen network structure is equipped into the proposed blockchain system architecture and integrated with Sarawak's pepper value chain as a form of digitalization towards the Sarawak's pepper industry.

CHAPTER 5: EVALUATION AND IMPLEMENTATION OF NETWORK STRUCTURES IN PBFT CONSENSUS ALGORITHM

With the qualitative findings presented in Chapter 4, blockchain technology is getting more promising to be the main driver in alleviating pain points such as the following:

(1) the lack of product transparency, which may lose its stringent quality when passing to several stages without an automated supervision, and

(2) the lack of clear visibility of alternative linkages, especially to stakeholders that were not directly connected in the pepper value chain.

Therefore, it is important to study the underlying consensus utilized in the BCN and its metrics, which was experimented based on the suggested PBFT consensus algorithm.

As such, this chapter describes how the PBFT consensus algorithm and selected network structures were programmed and compared in terms of performance, scalability, and reliability (PSR) metrics to gauge the overall efficiency of the proposed network structures. Subsequently, the combination of the group and layer network structures are introduced with additional mechanisms in countering faulty primary or replica nodes during the transactional process. Additionally, a system architecture was drawn to reveal the inner technologies and concepts involved in the devised BCN.

5.1 Subjects, Tools, and Procedures

Based on the discussions of PBFT in subchapter 2.8, the following test were conducted with three different network structures. In Figure 5.1, the structure was basically the vanilla PBFT without additional customization. In Figure 5.2, the structure was the network nodes fragmented into segregated groups, meaning there were more than one primary node and were formed into a constituted primary group, with each primary node having their own replica nodes. In Figure 5.3, the structure was the primary nodes branched and chained in an imaginary line. All replica nodes were arranged in each knot of the layer to the assigned primary node, eventually producing linked layers with connected primary nodes as the main linkage of broadcasting transaction requests.

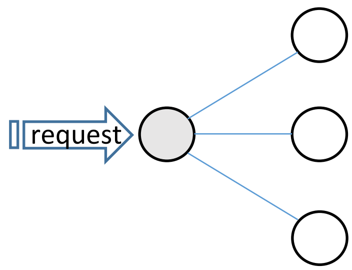


Figure 5.1 The basic network structure (grey = primary)

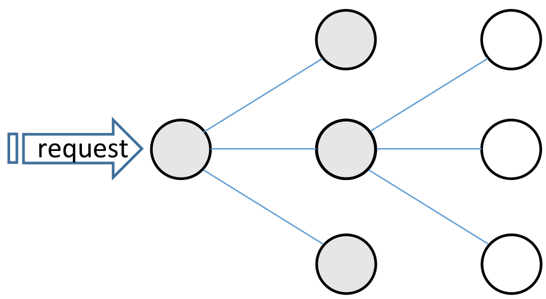


Figure 5.2 The group network structure (white = replica nodes)

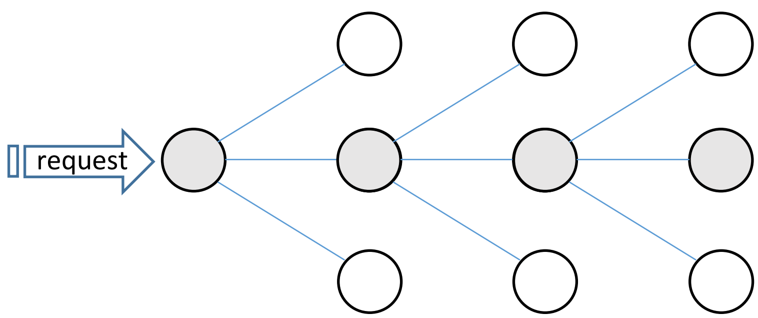


Figure 5.3 The layer network structure (only show a branch)

The experiment was conducted using a Core i7 (7700HQ) Intel Mobile Processor with 8GB RAM (2400MHZ) to provide a better simulation when opening duplicate applications in a single launch. In Figure C2, the applications were terminal windows that served as network nodes for the PBFT simulator, which were launched together by executing a Windows batch script with assigned node IDs of Appendix C. The three PBFT simulators: basic network structure, group network structure, and layer network structure were all programmed in Go programming language, which has been known for creating decentralized web applications with in-house features provided such as producing asynchronous threads with goroutines for task concurrency and the testing package for runtime benchmarking, and Visual Studio Code as the code editor for the entire work development.

Initially, the total number of nodes participated in the PBFT consensus algorithm had to be decided. With four network nodes and a client node as the minimum requirement of the total participation, it was decided to allow 129 network nodes, including the client node to be the maximum amount of participation for the experiment as sudden latency had appeared to be more apparent while launching the CMD windows simultaneously. To simplify, the number of network nodes decided in the three PBFT simulators were ranged from 2^2 to 2^7, excluding the client node.

In terms of metrics, the experiment was conducted to observe the three following aspects of the PBFT consensus algorithm with different network structures: namely the performance, scalability, and reliability. Performance was measured by recurring transactions for any boosts or throttles during the process. Scalability is essentially increasing the number of nodes while measuring the completion time per completed transaction, as shown in Figure C3 of Appendix C. At the same time, reliability will be determined based on how many data packets received with correct digest, message sequence, and key verification. Any anomalies will also be recorded into designated penalty files assigned with node IDs, as shown in Figure C4 of Appendix C. With the recorded data from each aspect of the consensus algorithm, a direct comparison can be made by charting a line graph and interpret their overall efficiency in completing the simulated transactions.

5.1.1 Consensus Simulator

In depth, consensus simulator was capable in creating and running multiple nodes, which in this experiment would be known as multiple terminal windows. Within each terminal window, automated procedures were executed to undergo these pre-defined consensus phases: request, pre-prepare, prepare, commit, and reply. The results collected were the time taken to receive majority votes of acceptance for each transaction in milliseconds, and for each metric was conducted in different methods. For instance, performance metric was determined by solely recording the time taken from a batch of transactions, e.g. 20 transactions, then gradually incrementing allocated transactions until it reached a certain saturation or distinction of results between different network structures. The scalability metric was determined by incrementing number of network nodes for every recurrent test, obtaining the results, then observing for any hampering in TPS that was caused by populating nodes to the simulator. The overall objective for this simulator is solely prioritized on allowing a client node to broadcast transaction requests and receive responses from all replica nodes, *n* or until a minimum consensus has been achieved, using Eq. (5.1) as the decisive formula.

$$m_c = \frac{n-1}{3} + 1 \tag{5.1}$$

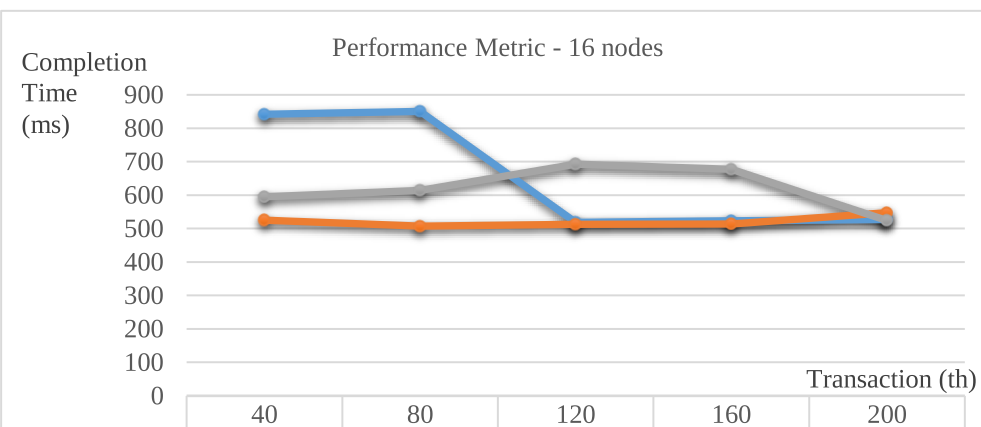
where m_c is the minimum consensus achieved and n is the total replica nodes in the consensus simulator.

5.2 Performance Metric

Generally, the performance metric is to manifest how the network structures were able to process the increasing amount of transactions with the minimum of time required to receive the minimum consensus being received by the client to approve each pending transaction. The time taken to process/consent transactions and broadcast were taken into consideration, along with how well each replica node was interacted in the network without faulty operations such as a lost packet, incorrect message sequence, and failure in digest-key verification for the reliability metric. Actual chaining of blocks and data recording/archiving by the storage nodes were not included in the experiment.

In this performance test, a total of 16 network nodes was evaluated in three different network structures. The network structures were evaluated individually in the literature but never against each other. All network nodes were continuously fed with a total of 200 transaction requests from a designated client node, with a new transaction request being produced after each 10 seconds by the client node since the experiment was conducted on a single machine to prevent bottlenecks and achieve consistent results. The main objective is to evaluate the stability of the consensus mechanism when operates in a prolong period by comparing the total execution of completing between each 40th transaction request to get the best average of results in each round of testing. A total of four iterations were made for each test, e.g. 4 * 200 transactions, with the result for each iteration being added together, then averaged to obtain the final result.

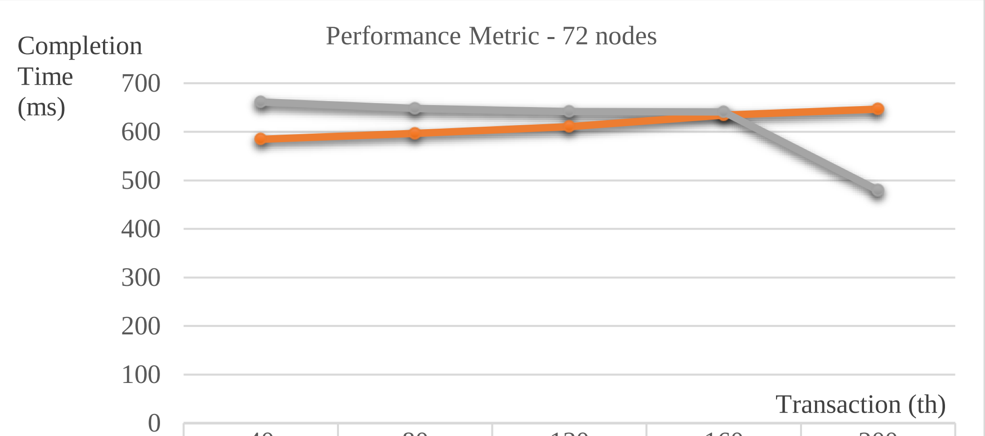
Figure 5.4 is a line graph with the completion time as the major factor of the performance metric between the basic, group, and layer network structures. It shows that the group network structure had the least completion time through all the 200 simulated transactions, followed by the layer network structure with approximately 600 milliseconds in completing a simulated transaction. The basic network structure had the most completion time as compared with the other network structures and was able to be on par with the layer network structure in terms of long-term system durability. However, it suffered in the latter experiment by having continuous packet loses and incorrect message sequence due to the bottleneck suffered in the primary node, primarily due to broadcasting and consenting at the same time. Therefore, it is not particularly suitable in having more than 16 replica nodes in the ongoing experiment.



	40	80	120	160	200
Basic	841.6374	850.4368	518.8311	523.2031	527.1905
Group	525.2947	507.419	512.924	514.0249	547.6852
Layer	595.3014	613.9129	692.7365	677.3739	524.1886

Figure 5.4 Performance test for basic, group, and layer network structures with a total of 16 network nodes

Figure 5.5 indicates that the group and layer network structures were the only participants to compete against each other, with 72 allocated network nodes per network structure. Based on the pattern, it is ascertaining that both network structures were able to sustain the continuous injection of transaction requests within the PBFT consensus algorithm. Again, the group network structure was able to process the majority of the transaction requests in lesser completion time compared to the layer network structure. Although the layer network structure managed to complete the 200th transaction request within 479 milliseconds, the group network structure was able to run 200 transactions with 84 allocated network nodes simultaneously. However, in the current machine, both network structures were unable to process the maximum total of 128 network nodes as prescribed in subchapter 5.1 due to the similar circumstances faced by the previous basic network structure, which were the data packet loses and incorrect message sequence. To conclude, the group network structure is the overall victor in the performance category as it is capable to process more than 72 replica nodes compared to the layer network structure.



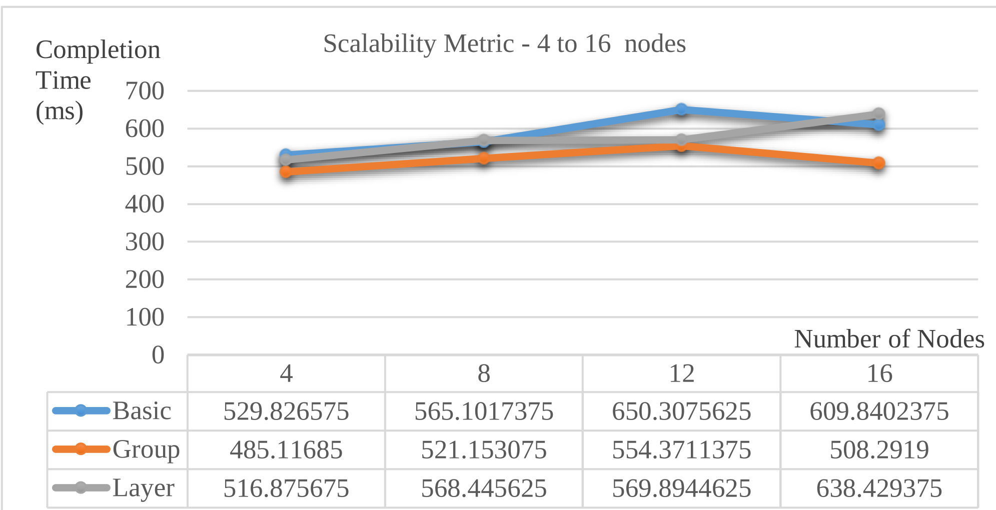
	40	80	120	160	200
Group	584.5694	596.5519	610.3381	634.4676	646.6641
Layer	661.4659	648.1285	641.4196	640.6927	479.5846

Figure 5.5 Performance test for group and layer network structures with a total of 72 network nodes

5.3 Scalability Metric

As for the scalability metric, its purpose is to determine the minimum of time required to process transactions while increasing the amount of replica nodes for each recurrent test, then observe the pattern drawn on the line graph to justify the capability of the network structure handling the total number of network nodes. The scalability test was progressed with an ascending sequence, starting from a total number of 2^2 to 2^6 network nodes. The results were obtained by averaging the completion time based on four iterations of 100 completed transactions, then compared amongst the basic, group, and layer network structures.

Figure 5.6 is a line graph with the completion time as the major factor of the scalability metric between the basic, group, and layer network structures. It demonstrates that the group network structure preserved a lower completion time compared to the basic and layer network structure. The layer network structure was gradually increasing its completion time upon adding network nodes to the experiment while the basic and group network structures were shown with a downturn when having 16 network nodes in the simulation, which is caused by the recurrent tests; from the tests of 4 – 12 network nodes that rendered shorter time towards the last test. As mentioned in subchapter 5.1, the basic network structure was unable to participate in the latter experiment due to node latency that caused inherent issues such as data packet loses and incorrect message sequence.



	4	8	12	16
Basic	529.826575	565.1017375	650.3075625	609.8402375
Group	485.11685	521.153075	554.3711375	508.2919
Layer	516.875675	568.445625	569.8944625	638.429375

Figure 5.6 Scalability test for basic, group, and layer network structures from 4 to 16 network nodes

Figure 5.7 shows both network structures were having the similar and stable line patterns, with the group network structure requiring the overall lesser completion time. Between 48 and 56 for the layer network structure and between 56 and 64 for the group network structure from the x-axis, the decrease in completion time proved that the slight increase of network nodes will not dampen the efficiency of the PBFT consensus algorithm with these two network structures as the building foundation.

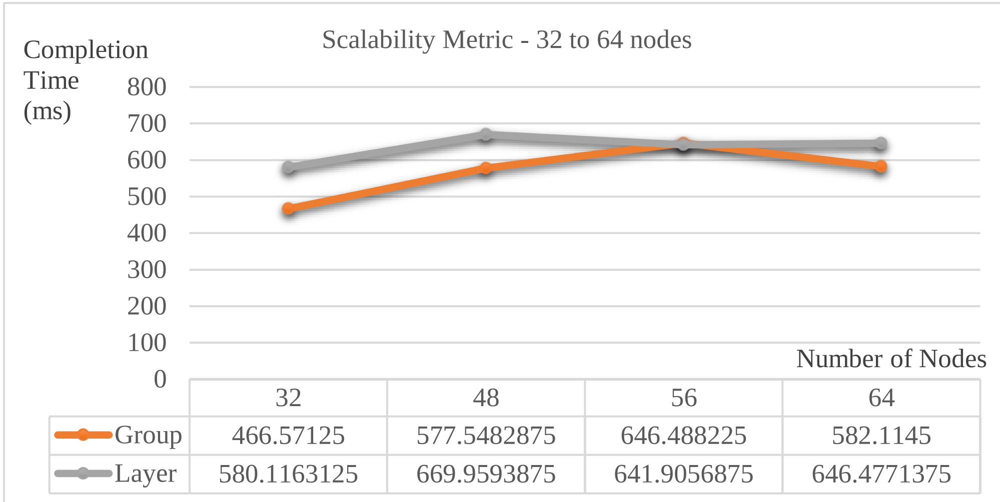


Figure 5.7 Scalability test for group and layer network structures from 32 to 64 network nodes

5.4 Reliability Metric

The reliability test was initiated to discover any faulty operations between node phases. A fault can be a lost packet, an incorrect message sequence, or a failure in digest-key verification. All notable faults were exported to designated node files to determine the severity of a lagged node. As this metric is all about true or false (0 or 1) basis, graphs will not be provided in this particular section. Once a fault is discovered, the network structure is considered ineligible to handle that amount of network nodes.

Throughout the performance and scalability experiments, the basic network structure was the only subject that was unable to progress the experiment with more than 16 network nodes, specifically with 20 network nodes in the experiment, thus making it the least reliable network structure to construct in a consensus mechanism. On the other hand, the group and layer network structure were able to handle up to 72 network nodes in the experiment, with the group network structure having the slight advantage in consensus speed and the additional of 12 consensus nodes allowed in the mechanism. Overall, the group network structure proves to be reliable and therefore, it is chosen to be part of the PBFT consensus algorithm for the blockchain system architecture.

5.5 Proposed Network Structure and Mechanisms

The following is the comprehensive network structure that describes and illustrates the actual flow of a transaction request and the allocation of network nodes in sequence groups. Based on the experimental results, the group network structure has the least completion time in majority of the test. Hence, the proposed network structure will be segmented into groups.

Figure 5.8 exhibits 3 significant groups: relay, consensus, and pending groups. Each group is tasked with different functionalities and distinct roles. First and foremost, the uppermost group consists of relay nodes, which can be represented by localized servers stationed at MPB branches. Relay machines or localized servers are used to relay transaction requests without participating any ongoing consensus from the client. In addition, MPB branch can register new participants by linking to the localized servers with office computers and update the member listing in the form of Windows GUI. Secondly, the consensus group comprises of primary nodes (grey) and replica nodes (white), with each segment allocated with one primary and three replica nodes. For the purpose of illustration, three replica nodes are allocated, which in reality can be added to a certain capped amount. The actual capped amount is not available as the prototype is not being tested and developed at the time of writing.

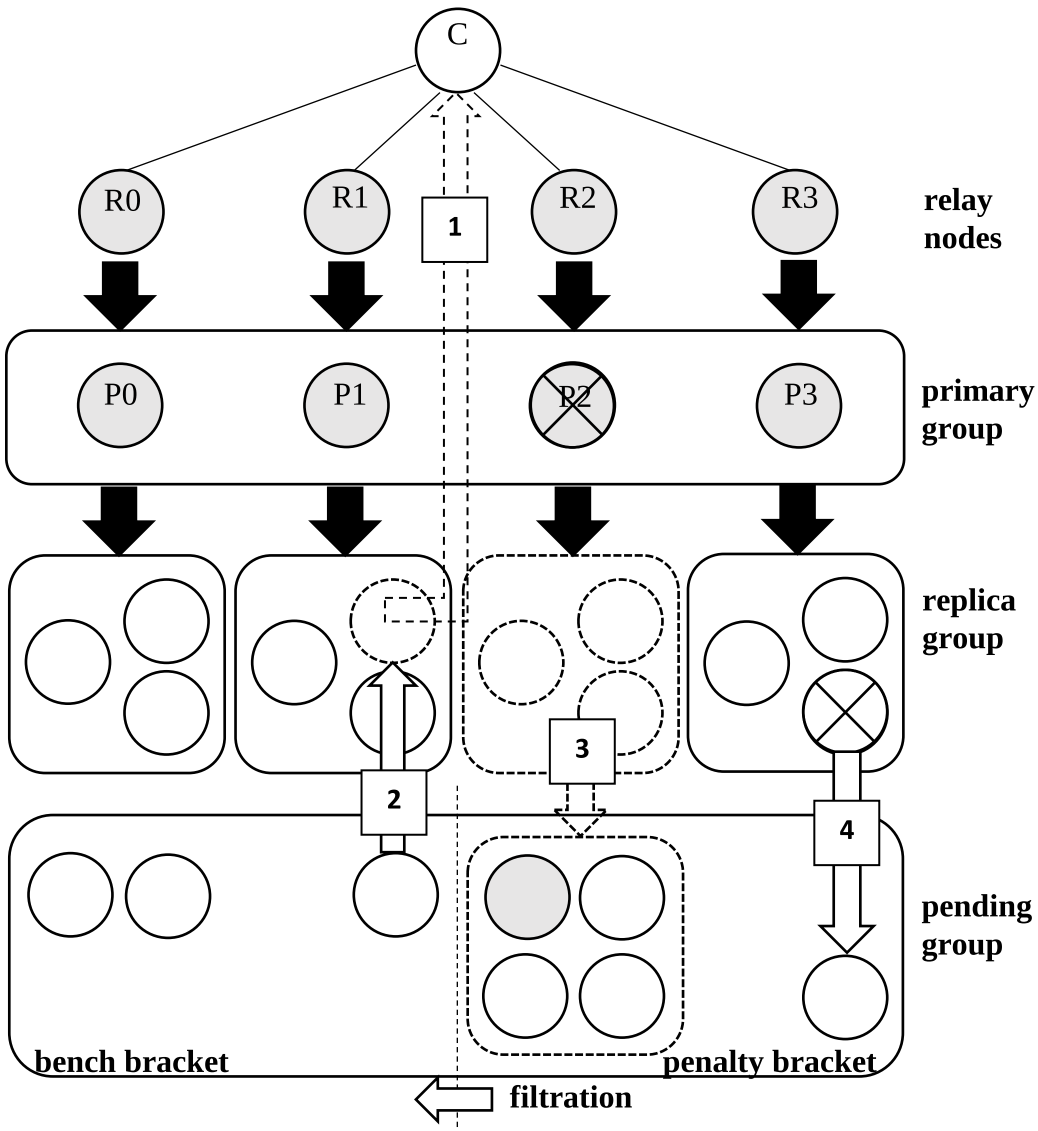


Figure 5.8 Group Network Structure with Node Penalty and Filtration System

As shown in Figure 5.8, multiple consensus groups can be formed in this PBFT consensus mechanism. Primary nodes in the group will multicast the transaction request from the designated relay node to its party members (replica nodes) located in the replica group. The furthermost group in the layout is called the pending group, whereby nodes are divided between two brackets: namely the penalty and bench. Network nodes that were caught having multiple faults will be sent to the penalty bracket and waiting to be filtered by the MPB administration panel, mostly by cross-referencing its message logs and the condition of the device. Any irregularities in the message logs will be deleted and be given an updated copy of the blockchain from the administrator. After the filtration, the refreshed node will be sent to the bench bracket, waiting to be formed a new party with other replica nodes with the corresponding district relay node. For instance, Miri district pepper stakeholders will be placed under the management of Miri's relay nodes.

Notice that there are numbered boxes labelled in Figure 5.8. The 1st numbered box is when the node has made a transaction request, it will automatically become the client. When that happens, a node from the bench bracket will be immediately placed into the empty slot, as shown by the arrow with the 2nd numbered box. In any case that there are no replacements for the empty slot, the segment will continue the normal-case operation as planned. Subsequently, the 3rd numbered box is when a primary node has attempted multiple faults such as unresponsiveness and malicious acts, the entire segment will be relocated to the penalty bracket and be filtered accordingly. As for the 4th numbered box, the replica node that caused multiple faults will be sent to penalty bracket as opposed to the entire segment. At the same time, a replacement will be made by funneling a bench node to the vacant slot, on the condition of having the similar district. As a clear distinction, the allocation of relay nodes in accordance to Sarawak's districts along with the Node Penalty and Filtration System are differentiated from the existing network structure in the literature to provide additional security and protective mechanisms to the BCN.

5.6 Proposed System Architecture

The underlying architecture of the BCN for Sarawak's pepper industry is depicted in Figure 5.9 with these 5 main principles, which are the application, blockchain, consensus mechanism, communication, and types of network nodes.

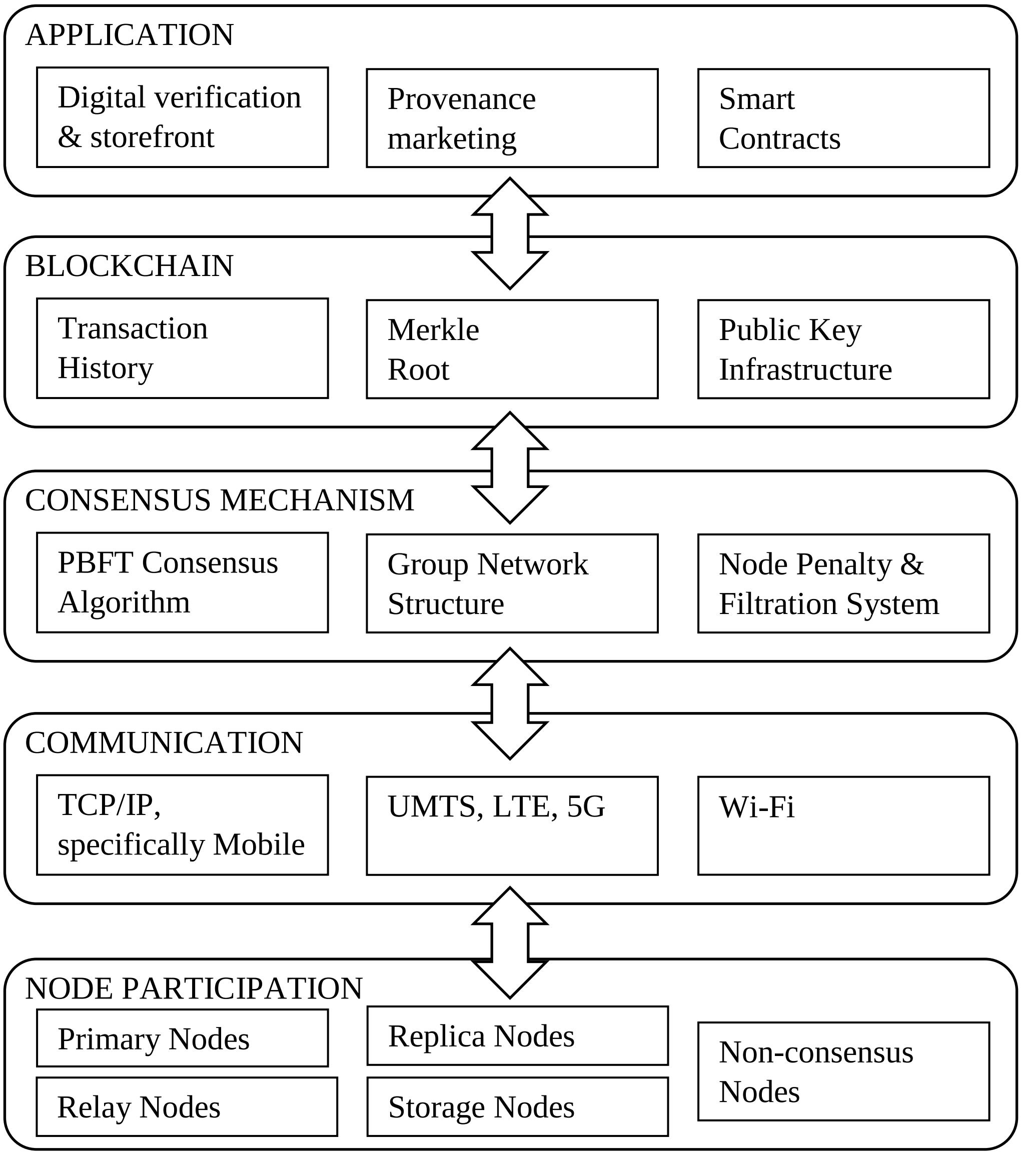


Figure 5.9 An overlay of the PBFT blockchain system architecture

In mutual blockchains, primary and replica nodes are the essential workers in participating consensus. With the current network structure, relay and storage nodes are added and utilized in carrying administration and data sharing without participating in the consensus. Participating nodes were instructed to mainly conduct consensus operation, with only recent transactions being stored in the device storage to avoid accumulation on low-storage devices and able to view a portion of recent data in an offline environment. Any other participants that are not willing or unable to join the consensus due to the lack of internet connectivity or telecommunication infrastructure will be categorized as non-consensus nodes. Although considered as inactive workers, they are allowed to initiate transaction requests and will be getting periodic updates on any data creation and alteration. As Sarawak's Pepper permissioned blockchain is intended to build for mobile devices, i.e. smartphones and tablets, all consensus nodes will be receiving incentives as a form of appreciation in contributing additional power consumption of mobile CPU, excluding storage and relay nodes, which are not conducting any form of consensus operations. Incentives can be in the form of digital tokens and be used in buying pepper-related products through transaction requests. Every device (network) node will be listening and sending requests via TCP/IP, and requires at least a 3G-enabled mobile devices (UMTS) to interact in the blockchain platform. Alternatively, Wi-Fi signal is recommended to provide a fixed and stable connectivity in continuing consensus. All consensus is performed by conducting the normal-case operation of PBFT consensus algorithm, with the group network structure as a blueprint for node arrangements and the Penalty Filtration system to recover faulty nodes within the system. Faulty nodes can be recovered by checking their device performance and replacing corrupted data from the storage node, which contains transaction history, hashed into a Merkle tree, encrypted, and chained in subsequent blocks. Ultimately, pepper stakeholders can use Sarawak's Pepper blockchain application to create digital presence, which is beneficial in boosting market values and automating sales by deploying smart contracts in a seamless user interface. Alternatively, the proposed layout can also be interchanged by tracing the components utilized in these two application sectors: AgriDigital [70] and AgUnity [71]. These sections have been discussed precisely in subchapter 2.5.4.

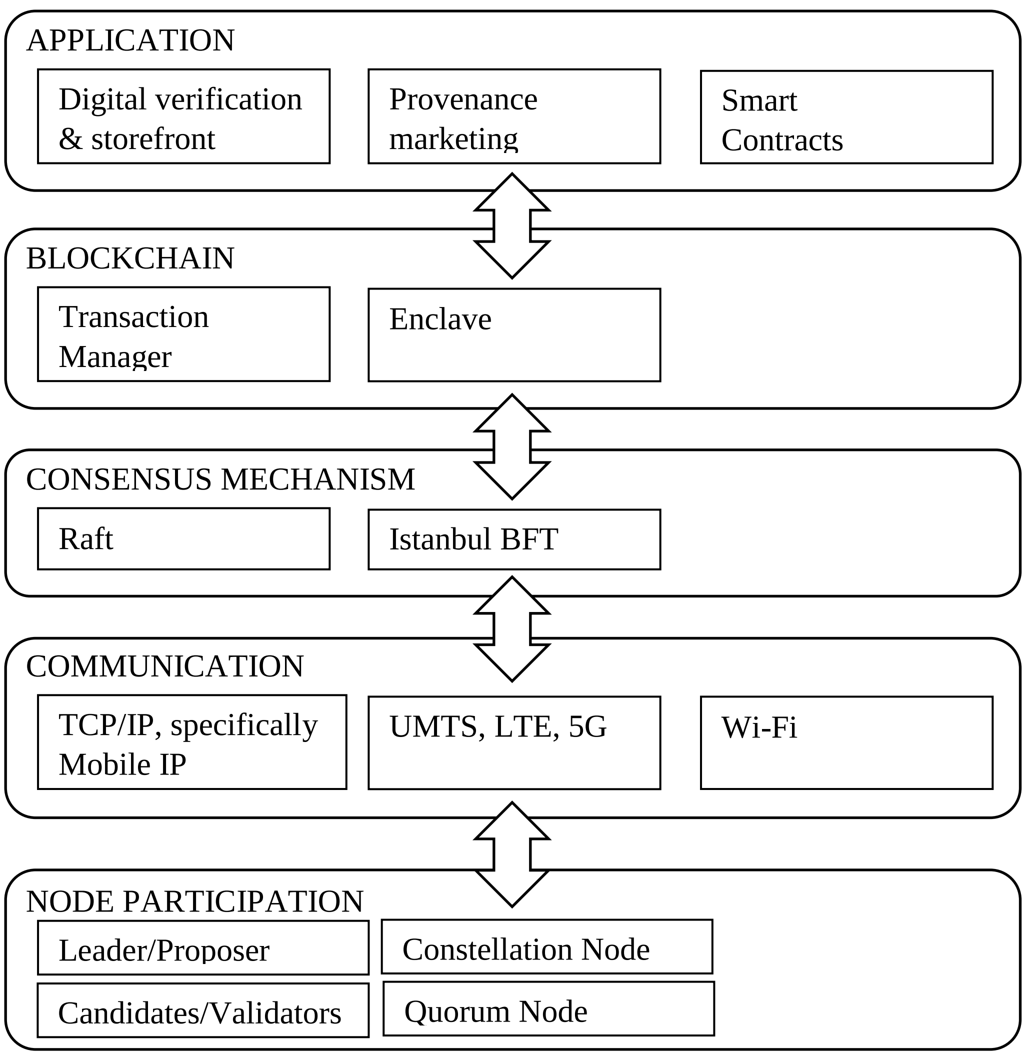


Figure 5.10 An overlay of the Quorum-based blockchain system architecture [74] by AgriDigital

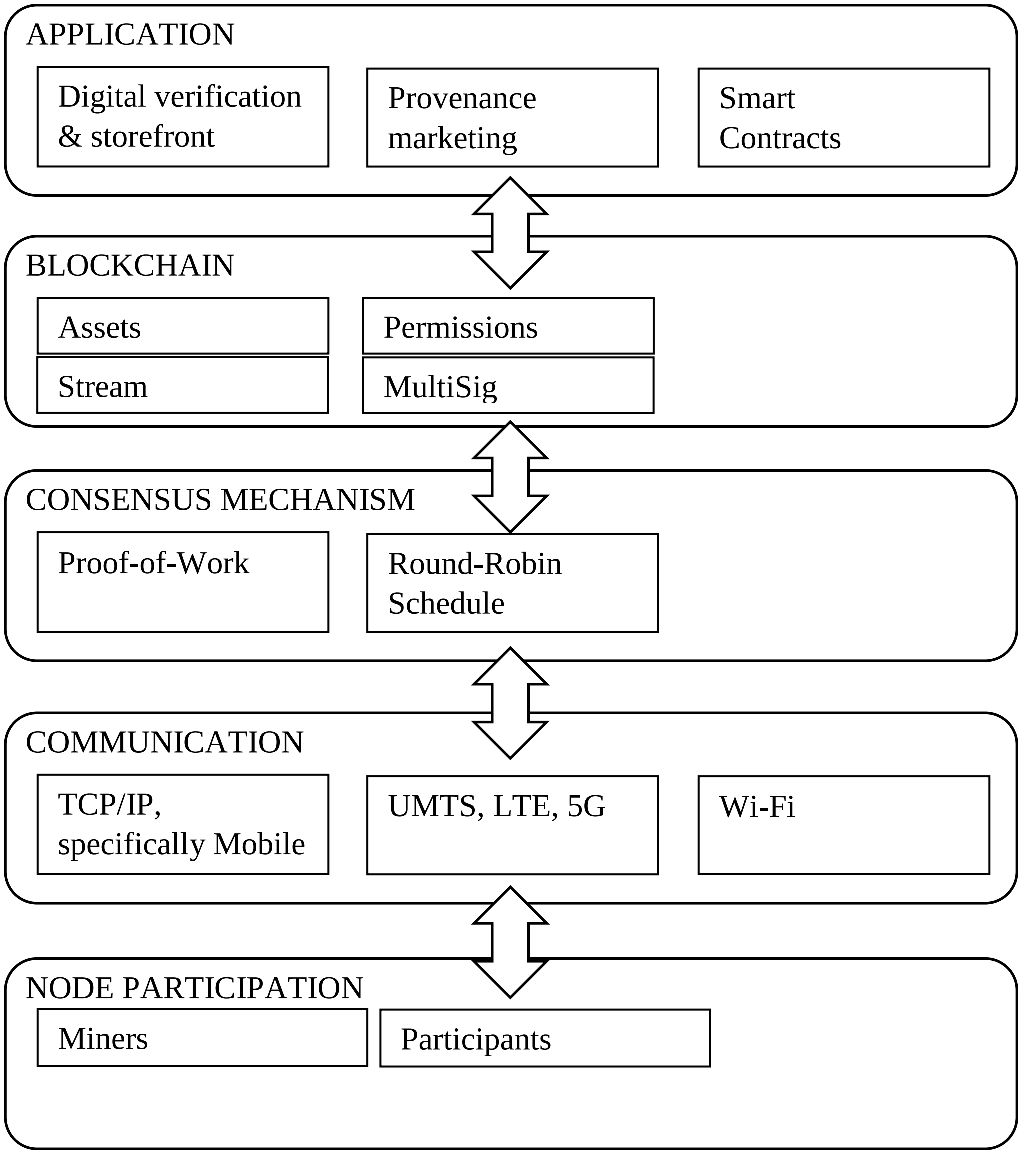


Figure 5.11 An overlay of the Multichain-based blockchain system architecture [78] by AgUnity

By comparison, the major distinction is between the consensus mechanism of different blockchain system architectures. In the proposed blockchain system architecture, the Practical Byzantine Fault Tolerance (PBFT) is implemented along with minor configurations, which are the Group network structure and the Penalty Fitration system to better facilitate the node arrangements. In Quorum-based blockchain system architecture, it utilized either the Raft consensus algorithm, a simplification derived from the Paxos consensus algorithm or Istanbul BFT, an inspiration noted from the Clique's Proof of Authority (PoA), which depends on developers to opt for a faster transaction speed or a better security mechanism amongst the network nodes. In Multichain-based blockchain system architecture, Proof of Work is employed with round-robin scheduling to prevent the same miner from minting blocks consecutively. A summarization between the comparison is shown as Table 5.1.

Table 5.1: A comparison between the consensus mechanism of different blockchain system architectures

Proposed	**Quorum**	**Multichain**
Practical Byzantine Fault Tolerance (PBFT)	Raft / Istanbul BFT	Proof of Work
Group network structure		Round-Robin Schedule
Penalty Filtration system		

5.7 Application of Blockchain Technology

The proposed consensus algorithm helps to strengthen the security mechanism of the BCN. Hence, every stakeholder included inside Sarawak's pepper value chain will have the opportunity to upscale the digital presence by participating the BCN through a blockchain mobile application without doubting the security mechanism during pepper transacting. Aside from the software developments, RFID and NFC are projected to be integrated in the blockchain system and utilized within these respective groups: processors-wholesalers and wholesalers-retailers. When delivering a bulk of pepper in gunny sacks by licensed processors, a RFID tag will be placed with a Unique Identification (UID), then scanned across with a RFID scanner, which signifies the selected sack is ready to be transported. An example of the RFID application is shown in Figure 5.13.

Once the product has reached to a licensed wholesaler, the product will be scanned again to confirm the arrival of package. Eventually, information will be maintained in a shared database and accessible to all consumers, as they can simply scan the NFC sticker labeled outside the packaged goods to ensure food safety and reduce food frauds. For instance, the lid of the pepper packaging will be laminated with a NFC sticker that can be scanned to verify the product integrity. Once the sticker is peeled off upon removal of the packaging, the antenna strip will be disconnected and deemed as a useless state. This precaution can ensure the content can always be authenticated and the content cannot be tampered with, thus reducing the case of food frauds [122]. Additionally, tracing mechanisms may allow consumers to provide feedback and offer optional e-Support to smallholder farmers as a mean of supporting local farmers and producers.

Figure 5.12 shows a visualization on the real-case operation of the BCN with RFID and NFC as the integrated wireless technology for provenance tracking. Through this layout, individuals are able to be cognizant about the product integrity before purchasing. Alternatively, buyers that are not equipped with a NFC-enabled smartphone can opt for QR scan to view the similar information from the blockchain database, as shown in Figure 5.13. The application is purposely useful for individuals, regardless of the participation in the BCN to identify the originality of the pepper product without having to guess its authenticity amidst purchase decision process. It is also proved to be user-friendly, which can simply scan on the anti-tampered seal imprinted with NFC and QR labels to retrieve product information from external shared databases that was encrypted and provided by the storage nodes in the BCN.

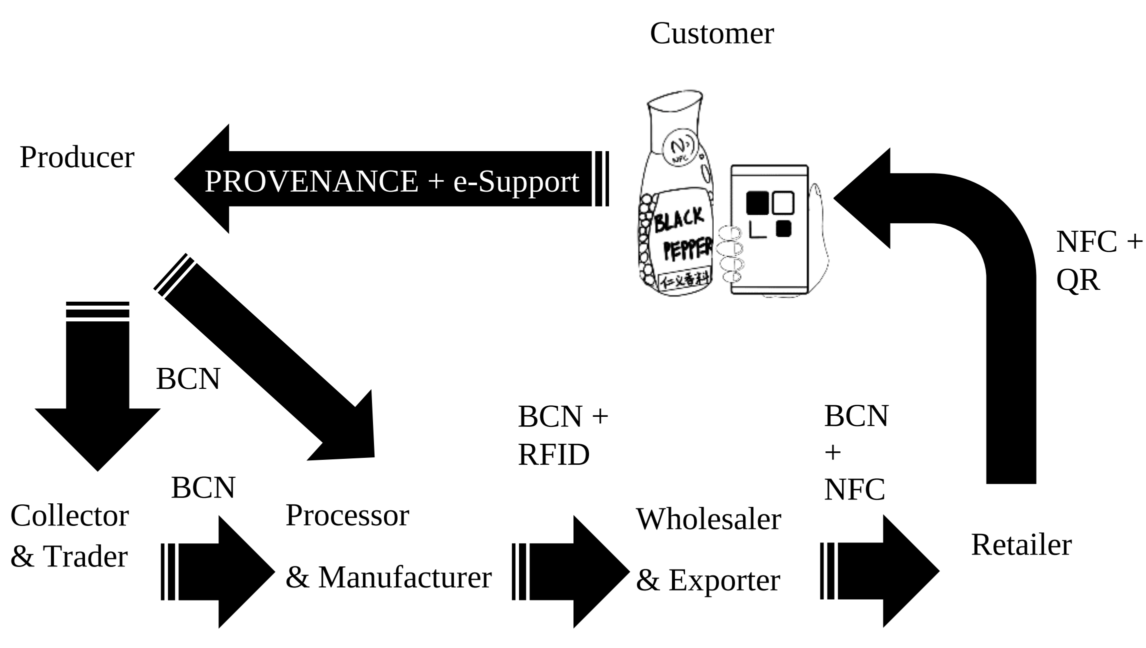


Figure 5.12 A digitalized Sarawak's pepper value chain

Figure 5.13 A RFID tag for the gunny bag and NFC anti-counterfeiting label with embedded QR code

Source: Adapted from [123] and [124]

Despite all the advantages, majority of pepper stakeholders are unaware of blockchain technology and may perceive as a concept that is difficult to master in practicality. Henceforth, the MPB may introduce blockchain and radio-frequency technology to a minor portion of pepper stakeholders to participate and transact inside the blockchain mobile application as a technical test and gain feedbacks among the participants.

CHAPTER 6: CONCLUSIONS AND FUTURE WORK

6.1 Conclusions

In Chapter 1, an introduction was made to outline the economy status of Sarawak's pepper industry. Throughout the preliminary research, it was acknowledged that Sarawak's pepper value chain had yet to be identified from local researchers and eventually became part of the research objectives. The main components for Sarawak's pepper value chain were the linkages and pain points of pepper stakeholders. In the meantime, the foundation of blockchain infrastructure was also in the research area and proposed to be integrated into the finalized Sarawak's pepper value chain. The core element of blockchain: the consensus algorithm, was chosen to be the theme for the second research objective, which was to evaluate variants of network structures of PBFT consensus algorithm. PBFT consensus algorithm is the befitting algorithm for empowering a small-scale blockchain with semi-authorization for this particular industry. The third research objective was to manifest the blockchain architecture with the chosen network structure and illustrate the digitalization of Sarawak's pepper value chain. With the fulfilment on these three research objectives, the proposed value chain and its consensus algorithm were considered verified and marked the end of research.

In Chapter 2, literature reviews were made, starting by extracting the definition of value chain and agricultural value chain. Concomitantly, numerical data for the total pepper production and export were also extracted to compile a ranked list for the pepper-producing countries, which helps to narrow the search for finding the established pepper value chains. The findings were enlisted under case studies and detailed the daily operation of pepper stakeholders, including their quotidian interactivities and difficulties. In addition, fundamental knowledge of blockchain technology was also being researched and explained regarding its data structure, especial features, and normal-use cases in real-life implementation, including towards the revolutionary of agricultural industry. Subsequently, research papers related to consensus algorithms, especially the PBFT consensus algorithm, were sought and reviewed to understand the operability of network nodes by referring to its normal-case operation, along with the derived variants of PBFT.

In Chapter 3, methods for conducting the research were mentioned, including how qualitative data was collected: structured interviews (primary data) and desktop studies (secondary data). When accessing qualitative interviews, a technique called snowball sampling was deployed to gather subsequent stakeholders that connects all selected participants in a chain, eventually leading to the final stakeholder category. To understand the research structure even further, a research framework was provided by itemizing the research process into different phases and were arranged in a systematic flow. Besides, the ethical consideration and guidelines were provided to be applied and implemented during the qualitative interviews.

In Chapter 4, all findings from selected participants were given, starting with their demographic profiles. Following up were the characteristics and roles of Sarawak's pepper value chain actors, with design structure of Sarawak's pepper value chain as the latter, where totalling 18 stakeholders had been discovered and were bridged into a completed value chain. In a separate page, the value chain was segmented into constituent linkages and shown in a table format. As additional information, average pricing for the black pepper was imparted to comprehend the influence on choosing subsequent buyers based on the price factor. Subsequently, pain points were described and compared based on the weighting system, which differentiates the significance of one pain point to another. In addition, the collected pain points were also referred to pain points from foreign pepper value chains and justified in subchapter 4.5.

In Chapter 5, network structures in PBFT consensus algorithm were evaluated, namely the basic, group, and layer network structures. All network structures were evaluated based on the PSR metrics, and were compared with time taken as the responding variable of the experiment, except for reliability, which was determined once an anomaly has reached. All results were tabulated and charted into a line graph for better comparison. Results showed that the group network structure succeeded in surviving the stress test environment, which was equipped with 84 replica nodes in the simulated BCN with less than 1 second per transaction. Therefore, the group network structure was appraised and considered as a robust technique in maintaining the long-term blockchain system for Sarawak's pepper industry. Additionally, proposed blockchain system architecture and digitalized Sarawak's pepper value chain were drawn to visualize the inner workings of the software layer and the interactions between existing technologies in the visible surface, thus verified the practicality and the research of the proposed value chain and its consensus algorithm. Lastly, a comparison between the proposed, Quorum-based, and Multichain-based blockchain system architecture was made to elaborate the differences of the consensus mechanism utilized between each other.

6.2 Recommendations for Future Works

Despite the completed simulation, actual development and a pilot programme of Sarawak's pepper blockchain application to selected participants are necessitated to gain feedbacks in regard to the feasibility, practicality, and stability of the running mechanism. For instance, the MPB can collaborate with Sarawak Digital Economy Corporation (SDEC) to lead the blockchain initiative and enlighten pepper stakeholders to pursue digitalisation in their business operation by encouraging them to join the pilot programme. As for any subsequent research works, new testbeds are recommended to trial the connectivity between machines when consenting transactions with wireless protocols that infused in the codebase and rerun the established theories. Another continuity of the research is to build a decentralized app (dApp) as the prototype for the Sarawak's pepper industry by utilizing the proposed consensus algorithm and its network structure. Moreover, the established the BCN can incorporate Internet of Things (IoT) devices to monitor the status of pepper commodity in the value chain. For instance, monitoring sensors can be scattered on pepper fields to survey the condition of the pepper crops by periodically transmitting data to an interconnected IoT gateway, e.g. a Raspberry Pi. The IoT gateway will then update those data to farmer’s dApp profile and be readily used when transacting with buyers, which is packaged together with the transaction request, then broadcasted to the members for consensus.

REFERENCES

[1] Department of Statistics Malaysia, "Selected Agricultural Indicators, Malaysia, 2018," December 31, 2018. [Online]. Available: https://dosm.gov.my/v1/index.php?r=column/cthemeByCat&cat=72&bul_id=UjYxeDNkZ0xOUjhFeHpna20wUUJOUT09&menu_id=Z0VTZGU1UHBUT1VJMFlpaXRRR0xpdz09.

[2] Malaysia's Open Data Portal, "Information on Black Pepper Industry," *Department of Statistics Malaysia*, 2019.

[3] O. A. Olalere, A. Nour, O. R. Alara, and M. M. Ahmad, "The Impact of Pepper Production on Malaysian Economy and the Need for Nutraceutical Diversification," *The National Conference for Postgraduate Research*, vol. 3, Sept, 2016.

[4] Malaysian Pepper Board, "Malaysian Pepper Board set to spice things up," July 8, 2020. [Online]. Available: https://www.mpb.gov.my/mpb/index.php/en/mpb-in-news/352-malaysian-pepper-board-set-to-spice-things-up

[5] "Farmers struggle with low prices," *The Borneo Post*, November 29, 2018. [Online]. Available: https://www.theborneopost.com/2018/11/29/farmers-struggle-with-low-prices/.

[6] L. Feng, H. Zhang, Y. Chen, and L. Lou, "Dynamic Multi-Agent Practical Byzantine Fault-Tolerant Consensus in Permissioned Blockchain," *Applied Sciences*, vol. 8, no. 10, Oct, 2018.

[7] K. Lei, Q. Zhang, L. Xu and Z. Qi, "Reputation-Based Byzantine Fault-Tolerance for Consortium Blockchain," *2018 IEEE 24th International Conference on Parallel and Distributed Systems (ICPADS)*, Singapore, Singapore, 2018, pp. 604-611.

[8] Y. Jiang and Z. Lian, "High Performance and Scalable Byzantine Fault Tolerance," *2019 IEEE 3rd Information Technology, Networking, Electronic and Automation Control Conference (ITNEC)*, Chengdu, China, 2019, pp. 1195-1202.

[9] S. Gao, T. Yu, J. Zhu and W. Cai, "T-PBFT: An EigenTrust-based practical Byzantine fault tolerance consensus algorithm," in China Communications, vol. 16, no. 12, pp. 111-123, Dec, 2019.

[10] MindTools, "Porter's Value Chain: Understanding How Value is Created within Organizations," mindtools.com. [Online]. Available: https://www.mindtools.com/pages/article/newSTR_66.htm.

[11] M. E. Porter, *Competitive Advantage: Creating and Sustaining Superior Performance,* New York: Free Press, 1985.

[12] UNIDO, *Agro-Value Chain Analysis and Development: The UNIDO Approach,* United Nations Industrial Development Organization, Vienna Press, 2009.

[13] P. M. Clay and R. J. Feeney, "Analyzing agribusiness value chains: A literature review," *International Food and Agribusiness Management Review,* vol. 22, no. 1, pp. 1-16, 26 October, 2018.

[14] W. Martin, *Using value chain approaches in agribusiness and agriculture in Sub-Saharan Africa. A methodological guider, Tool as that make vale chains work: Discussion and cases,* 2007.

[15] A. Hailu, "Value chain analysis of vegetables. The case of Ejere District, West Shoa Zone," M. S. thesis, Haramaya University, Oromia, Ethiopia, 2016.

[16] Food and Agriculture Organization, "Agricultural value chain development: Threat or opportunity for women's employment," 2010. [Online]. Available: http://www.fao.org/3/i2008e/i2008e04.pdf.

[17] H. Bammann, "Participatory value chain analysis for improved farmer incomes, employment opportunities and food security," Pacific Economic Bulletin, vol. 22, no. 3, pp. 113-125, 2007.

[18] German Technical Cooperation Agency, Value Links Manual – The Methodology of Value Chain Promotion – First Edition, 2007.

[19] A. Devaux, M. Torero, J. Donovan, and D. Horton, "Agricultural innovation and inclusive value-chain development: a review," Journal of Agribusiness in Developing and Emerging Economies, vol. 8, no. 1, pp. 99-123, 2018.

[20] V. Cuddeford, "An introduction to agricultural value chains," *Farm Radio International,* 2014. [Online]. Available: https://idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/52685/IDL-52685.pdf.

[21] J. A. Berdegué, "Cooperating to compete: associative peasant business firms in Chile," Ph.D. dissertation, Wageningen Agricultural University, Wageningen, Netherlands, 2001.

[22] R. Norton, "Agricultural value chains: A game changer for small holders," devex.com, 28 July, 2014. [Online]. Available: https://www.devex.com/news/agricultural-value-chains-a-game-changer-for-small-holders-83981.

[23] Klynveld Peat Marwick Goerdeler, *The agricultural and food value chain: Entering a new era of coorperation,* 2013. [Online]. Available: https://assets.kpmg/content/dam/kpmg/pdf/2013/06/agricultural-and-food-value-chain-v2.pdf.

[24] H. L. Tan, "The EU moves to reduce palm oil use. Malaysia hits back at 'politics of protectionism'," *Consumer News and Business Channel*, March 15, 2019. [Online].

Available: https://www.cnbc.com/2019/03/15/eu-moves-to-remove-palm-oil-in-transport-fuel-malaysia-hits-back.html.

[25] R. Cramb, and J. McCarthy, "Palm oil politics impede sustainability in Southeast Asia," *The Conversation*, April 20, 2016. [Online]. Available: https://theconversation.com/palm-oil-politics-impede-sustainability-in-southeast-asia-57647.

[26] G. Perwara and B. Munggaran, "Pepper Statistical Yearbook 2018," *International Pepper Community,* [Online]. Available: http://www.ipcnet.org/n/psy2018/html/link.html.

[27] P. Mu, "Malaysian Pepper Board to tap Middle East markets at Expo 2020 Dubai," New Straits Time, February 12, 2022. [Online]. Available: https://www.nst.com.my/news/nation/2022/02/770831/malaysian-pepper-board-tap-middle-east-markets-expo-2020-dubai#:~:text=The%20black%20pepper%20industry%20is,of%20pepper%20farmers%20across%20Malaysia.

[28] R. Allan, A. Daud, N. Teruki, A. Alwie, S. Hanim, and R. Alan, "Tracing the Growth of Sarawak Pepper," *International Journal of Academic Research in Business and Social Sciences,* vol. 11, no. 17, pp. 27– 34, October 20, 2021.

[29] A. A. Karimov, Nguyen Thi Thinh, J. J. Cadilhon, Truong Tan Khanh, Pham The Hue, Tran Van Thuy, Do Kieu An, Chau Thi Minh Long, and Dinh Thi Nha Truc. "Value chain assessment report for avocado, cattle, pepper and cassava in Dak Lak province of Central Highlands of Vietnam," *International Livestock Research Institute Project Report.* Nairobi, Kenya, Apr, 2016.

[30] K. Sim and K. L. Heng, "Memot Pepper Market System Analysis. Cambodian Institute for Research and Rural Development," Cambodian Institute for Research and Rural Development, Nov, 2015.

[31] M. Thibbotuwawa, J. Wijayasiri and D. Hirimuthugodage, "Analysis of Cinnamon, Pepper and Cardamon Value Chains in Sri Lanka," *Institute of Policy Studies of Sri Lanka,* Colombo, Sri Lanka, 2017.

[32] Y. Lak, "Value Chain Analysis of Memot Pepper in Cambodia," *Australasian Agribusiness Perspectives*, vol. 21, no. 2, pp. 24-42, 2018.

[33] N. Kumar, "Value Chain Analysis of Black Pepper in Karnataka," University of Agricultural Sciences, Bangalore, Karnataka, India, 2013.

[34] A. Kamilaris, A. Fonts, and F. Prenafeta Boldú, "The rise of blockchain technology in agriculture and food supply chains," Trends in Food and Science Technology, Jul, 2019.

[35] C. Addison, "Opportunities of blockchain for agriculture," *Brussels Rural Development Briefing,* 2019. [Online]. Available: https://brusselsbriefings.files.wordpress.com/2019/05/bb55-reader_blockchain-opportunities-for-agriculture_en.rev_.pdf.

[36] A. Rosic, "William Mougayar: The future of blockchain?," HuffPost, 26 January, 2017. [Online]. Available: https://www.huffpost.com/entry/william-mougayar-the-future-of-blockchain_b_588ab294e4b02d07f20d918a.

[37] T. Tomu, "Blockchain for agriculture," *Medium,* 4 November, 2019. [Online]. Available: https://medium.com/swlh/blockchain-for-agriculture-5b0a0baa0aa3.

[38] T. M. Tan, J. Salo, P. Ahokangas, V. Seppänen, and P. Sandner, "Revealing the Disintermediation Concept of Blockchain Technology: How Intermediaries Gain from Blockchain Adoption in a New Business Model," *IGI Global,* Jan, 2021.

[39] M. Mattern, "Exploring Blockchain Applications to Agricultural Finance," Consultative Group to Assist the Poor, 4 July, 2018. [Online]. Available: https://www.cgap.org/sites/default/files/researches/documents/Brief-Exploring-Blockchain-Applications-July-2018.pdf.

[40] S. Nakamoto, "Bitcoin: A peer-to-peer electronic cash system," 2018. [Online]. Available: https://bitcoin.org/bitcoin.pdf.

[41] S. Seebacher and R. Schüritz, "Blockchain technology as an enabler of service systems: A structured Literature Review," *8th International Conference on Exploring Service Science,* Apr, 2017.

[42] M. Shankar and P. Akshaya, "Hybrid Cryptographic Technique using RSA Algorithm and Scheduling Concepts," International Journal of Network Security and Its Application (IJNSA), vol.6, no.6, Nov, 2014.

[43] Cyware Hacker News, "Exploring the Differences between Symmetric and Asymmetric Encryption," *cyware.com,* November 30, 2019. [Online]. Available: https://cyware.com/news/exploring-the-differences-between-symmetric-and-asymmetric-encryption-8de86e8a.

[44] tutorialspoint "RSA Cryptosystem: Generation of RSA Key Pair," [Online]. Available: https://www.tutorialspoint.com/cryptography/public_key_encryption.htm.

[45] R. Sedgewick and K. Wayne, *Computer Science: An Interdisciplinary Approach,* 2^{nd} ed. Princeton, NJ: Pearson Higher Ed, 2017. [E-Book] Available: https://introcs.cs.princeton.edu/java/99crypto/.

[46] G. C. Kessler, *An Overview of Cryptography*. Boston, MA, United States, Auer Bach Publications, 1998.

[47] C. Hoffman, "What is a Checksum and Why Should You Care," *howtogeek.com,* September 30, 2019. [Online]. Available: https://www.howtogeek.com/363735/what-is-a-checksum-and-why-should-you-care/.

[48] A. Vlachou, C. Doulkeridis, D. Mavroeidis, and M. Vazirgiannis, "Designing a Peer-to-Peer Architecture for Distributed Image Retrieval," Adaptive Multimedial Retrieval: Retrieval, User, and Semantics, 5th International Workshop, Paris, France, 2007.

[49] P. Helo and Y. Hao, “Blockchains in operations and supply chains: A model and reference implementation,” *Computer and Industrial Engineering,* vol. 136, pp. 242-251, Oct, 2019.

[50] D. Ongaro and J. Ousterhout, “In Search of an Understandable Consensus Algorithm,” USENIX Annual Technical Conference, June, 2014. [Online]. Available: https://web.stanford.edu/~ouster/cgi-bin/papers/raft-atc14.

[51] R. P. Dos Santos, “Consensus Algorithm: A matter of complexity?,” Jun, 2018.

[52] S. J. Zhang, J. H. Lee, “Analysis of the main consensus protocols of blockchain,” 12 August, 2019.

[53] A. Wahab and W. Memood, “Survey of Consensus Protocols,” Oct, 2018. [Online]. Available: https://arxiv.org/ftp/arxiv/papers/1810/1810.03357.pdf.

[54] Z. J. Wang, T. Y. Wang, H. Hu, J. Gong, X. Ren, and Q. Y. Xiao, “Blockchain-based framework for improving supply chain traceability and information sharing in precast construction,” *Automation in Construction,* vol. 111, Mar, 2019.

[55] F. Hassan, A. Ali, S. Latif, J. Qadir, A. Kanhere, J. Singh, and J. Crowcroft, “Blockchain and The Future of the Internet: A Comprehensive Review,” arXiv preprint arXiv:1904.00733, 23 February, 2019.

[56] Horizen Academy, “Blockchain as a Data Structure”. [Online]. Available: https://academy.horizen.global/technology/advanced/blockchain-as-a-data-structure/.

[57] E. Scott, “Blockchain to trace agricultural supply chains,” *Fauna and Flora International,* 10 January, 2010. [Online]. Available: https://www.fauna-flora.org/news/blockchain-trace-agricultural-supply-chains.

[58] P. Osbourne, “Blockchain in Agriculture: New Vision for Agriculture Industry,” *Bitnews Today,* 24 January, 2020. [Online]. Available: https://bitnewstoday.com/news/blockchain-in-agriculture-new-vision-for-agriculture-industry/.

[59] G. Sylvester, “E-Agriculture in Action: Blockchain for Agriculture Opportunities and Challenges,” *The Food and Agriculture of the United Nations and the International Telecommunication Union Bangkok,* Feb, 2019.

[60] Plot11, China, Blockchain in Food Industry: Part 2. (Aug. 8, 2020). [Online]. Available: https://youtu.be/egFa6iTxN60.

[61] B. Haire, “Blockchain: Revolutionizing the agriculture industry,” Deloitte, October 2018. [Online]. Available: https://www2.deloitte.com/au/en/pages/consumer-business/articles/blockchain-revolutionising-agriculture-industry.html.

[62] A. Zainuddin, “Challenges in Blockchain Tehnology Today,” eTorox, 5 September, 2019. [Online]. Available: https://www.etorox.com/news/opinions/challenges-in-blockchain-technology-today/.

[63] T. K. Sharma, “5 Key Challenges for Blockchain Adoption in 2020,” Blockchain Council, 26 March, 2020. [Online]. Available: https://www.blockchain-council.org/blockchain/5-key-challenges-for-blockchain-adoption-in-2020/.

[64] A.L. Fajri and F. Mahananto, “Hybrid lightning protocol: An approach for blockchain scalability issue,” *Procedia Computer Science,* vol. 197, pp. 437-444, 2022.

[65] D. Van Flymen, “Learn blockchains by building one,” *Hackernoon,* 18 January, 2020. [Online]. Available: https://hackernoon.com/learn-blockchains-by-building-one-117428612f46.

[66] Binance Academy, “What is a blockchain consensus algorithm,” December 13, 2018. [Online]. Available: https://www.binance.vision/blockchain/what-is-a-blockchain-consensus-algorithm.

[67] A. De Vries, “Bitcoin's Growing Energy Problem,” Joule2, pp. 801–809, May 16, 2018.

[68] C. Kim, “3 Ways Staking Will Upend the Economics of Ethereum,” *Coindesk,* 25 October, 2019. [Online]. Available: https://www.coindesk.com/3-ways-staking-will-upend-the-economics-of-ethereum.

[69] A. Noel, “Six Ways Blockchain is Being Used in Food and Agriculture Supply Chains,” *Medium*, September 19, 2018. [Online]. Available: https://medium.com/cultivati/six-ways-blockchain-is-being-used-in-food-and-agriculture-supply-chains-68a7305fd533.

[70] Agridigital, “Trust and Transaprency for Agri Supply Chains,” [Online]. Available: https://www.agridigital.io/.

[71] AgUnity, “Connecting the Last Mile,” [Online]. Available: https://www.agunity.com/.

[72] P. Lau, “Grain on the Blockchain: How Digital supply chains are greening agriculture,” May 10, 2019. [Online]. Available: https://www.eco-business.com/news/grain-on-the-blockchain-how-digital-supply-chains-are-greening-agriculture/.

[73] ICT4Ag, “Perspectives for ICT and Agribusiness in ACP countries: Start-up financing, 3D printing and blockchain,” 2017. [Online]. Available: https://s3-eu-west-1.amazonaws.com/cta-scr-media/91e974bc-eebe-4558-ba02-fe0006606bbf.pdf.

[74] V. Saini, “Quorum 101: Getting started with Quorum,” May 3, 2018. [Online]. Available: https://hackernoon.com/quorum-101-getting-started-with-quorum-9906294ea45b.

[75] L. Pufahl, B. Ohlsson, G. Harper, E. Weston, and I. Weber, “Enabling Financing in Agricultural Supply Chains through Blockchain,” *Business Project Management Cases,* vol. 2, Mar, 2020.

[76] Grow Asia Digital Directory, “AgUnity: Capability and Features with Progress to Date,” [Online]. Available: https://growasiadirectory.org/agunity/.

[77] T. Tillemann, A. Price, G. Tillemann-Dick, and A. Knight, “The Blueprint for Blockchain and Social Innovation,” *New America*, January 22, 2019. [Online]. Available: https://www.newamerica.org/digital-impact-governance-inititiative/blockchain-trust-accelerator/reports/blueprint-blockchain-and-social-innovation/case-studies/.

[78] MultiChain, “Cold Nodes and Wallets,” [Online]. Available: https://www.multichain.com/developers/cold-nodes-wallets/.

[79] S. R. Murthy, A. Hadzic, K. Roll, and L. Khalil, “Agriledger & Agunity: An Economics of Mutuality case study,” Responsible Business Forum: The Economics of Mutuality, 18-19 May, 2018.

[80] G. Konstantopoulos, “Understanding Blockchain Fundamentals, Part 1: Byzantine Fault Tolerance,” December 1, 2017. [Online]. Available: https://medium.com/loom-network/understanding-blockchain-fundamentals-part-1-byzantine-fault-tolerance-245f46fe8419.

[81] H. L. Zhang, “Byzantine Fault Tolerance for Distributed Systems,” M. S. thesis, Cleveland State University, Ohio, USA, Apr, 2014.

[82] Binance Academy, “Byzantine Fault Tolerance Explained,” December 6, 2018. [Online]. Available: https://www.binance.vision/blockchain/byzantine-fault-tolerance-explained.

[83] L. Lamport, R. Shostak, and M. Pease, “The Byzantine Generals’ Problem,” *SRI International, ACM Transactions on Programming Languages and Systems*, vol. 4, no. 3, pp. 382-401, Jul, 1982.

[84] P. Kotamraju, “What is Byzantine Fault Tolerance?,” *tutorialspoint*, 25 April, 2019. [Online]. Available: https://www.tutorialspoint.com/what-is-byzantine-fault-tolerance.

[85] A. Tran, “A cursory introduction to Byzantine Fault Tolerance and Alternative Consensus,” *Medium*, 25 July, 2017. [Online]. Available: https://medium.com/@ancapalex/a-cursory-introduction-to-byzantine-fault-tolerance-and-alternative-consensus-1155a5594f18.

[86] M. Cao, “How to prevent Sybil Attacks without PoW/PoS,” *Medium*, December 4, 2019. [Online]. Available: https://medium.com/witnet/how-to-prevent-sybil-attacks-without-pow-pos-d4d72436dc85.

[87] M. Jakobsson, A. Juels “Proofs of Work and Bread Pudding Protocols,” In Proceedings of the IFIP TC6/TC11 Joint Working Conference on Secure Information Networks: Communications and Multimedia Security (CMS ’99), Kluwer, B.V., NLD, pp. 258–272, Sept, 1999.

[88] S. Seang and D. Torre, “Proof of Work and Proof of Stake consensus protocols: a blockchain application for local complementary currencies,” France: Universite Cote d'Azur-GREDEG-CNRS, vol.3, no.4, Feb, 2018.

[89] S. Goyal, "Here Is What You Need to Know About Blockchain Proof of Work," 101 Blockchains.com, 29 March, 2019. https://101blockchains.com/blockchain-proof-of-work/.

[90] A. Rosic, "Proof of Work Vs Proof of Stake: Basic Mining Guide," Blockgeeks.com, Mar, 2017. https://blockgeeks.com/guides/proof-of-work-vs-proof-of-stake/.

[91] M. Halas, "Blockchain technology as a part of Distribution System Operators' Platform Business Model," M. S. thesis, Lappeenrantha-Lahti University of Technology, 2019.

[92] R. R. O'Leary, "The Creator of Proof-of-Stake Thinks He Finally Figured It Out," Coindesk.com, 7 September, 2018. https://www.coindesk.com/the-creator-of-proof-of-stake-thinks-he-finally-figured-it-out.

[93] M. Castro and B. Liskov, "Practical Byzantine fault tolerance," In: Proceedings of the 3rd Symposium on Operating Systems Design and Implementation. New Orleans, USA: OSDI, 1999. pp. 173−186, Feb, 1999.

[94] L. Seeley, "Introduction to Sawtooth PBFT," *Hyperledger*, 19 February, 2019. [Online]. Available: https://www.hyperledger.org/blog/2019/02/13/introduction-to-sawtooth-pbft.

[95] CrushCrypto, "What is Practical Byzantine Fault Tolerance (PBFT)?". [Online]. Available: https://crushcrypto.com/what-is-practical-byzantine-fault-tolerance/.

[96] S. Chen, K.K.R. Choo, X. Fu, W. Lou, and A. Mohaisen, Eds., "Security and Privacy in Communication Networks," In: Proceedings of the 15th EAI International Conference, SecureComm 2019, Orlando, FL, USA, vol. 305, October 23–25, 2019.

[97] O. Onireti, L. Zhang, and M. A. Imran, "On the Viable Area of Wireless Practical Byzantine Fault Tolerance (PBFT) Blockchain Networks," *IEEE Global Communications Conference*, Waikoloa, HI, USA, Dec, 2019

[98] 2infiniti, "A Primer to LFT (Loop Tolerance) Consensus Algorithm," *Medium*, 4 October, 2018. [Online]. Available: https://medium.com/@2infiniti/a-primer-to-lft-loop-fault-tolerance-consensus-algorithm-d692bdece85a.

[99] IBM Knowledge Center, "Message digests and digital signatures". [Online]. Available: https://www.ibm.com/support/knowledgecenter/SSFKSJ_7.1.0/com.ibm.mq.doc/sy10510_.htm.

[100] M. Castro and B. Liskov, "Practical Byzantine Fault Tolerance and Proactive Recovery," *ACM Transactions on Computer Systems*, vol. 20, no. 4, pp. 398-461, Nov, 2002.

[101] A. Montresor. DS-BFT. Class Lecture, Topic: "Distributed Algorithms Practical Byzantine Fault Tolerance." School of Electrical and Computer Engineering, University of Trento, Trentino, Italy, Dec. 2, 2019.

[102] D. Gupta, "Towards Performance and Dependability Benchmarking of Distributed Fault Tolerance Protocols," System and Control, Université Grenoble Alpes, 5 October, 2016.

[103] R. Atkinson and J. Flint, “Accessing Hidden and Hard-to-Reach Populations: Snowball Research Strategies,” *Department of Sociology, University of Surrey*, 2001.

[104] W. P. Vogt, *Dictionary of Statistics and Methodology: A Nontechnical Guide for the Social Sciences*, London: Sage, 1999.

[105] M. Sanjari, F. Bahramnezhad, F. K. Fomani, M. Shoghi, M. A. Cheraghi, “Ethical challenges of researchers in qualitative studies: the necessity to develop a specific guideline,” *Journal of medical ethics and history of medicine,* vol. 7, no. 14, Aug, 2014.

[106] J. Wong, “Lucrative pepper farming,” *The Star*, June 8, 2016. [Online]. Available: https://www.thestar.com.my/metro/community/2016/06/08/lucrative-pepper-farming-prices-soar-as-more-people-use-the-spice-in-food-processing-and-manufacturi.

[107] Chin, “Agrobank, MPB sign agreement to offer financial aid to pepper smallholders,” *Borneo Post Online*, November 27, 2017. [Online]. Available: https://www.theborneopost.com/2017/11/27/agrobank-mpb-sign-agreement-to-offer-financial-aid-to-pepper-smallholders/.

[108] Curtin University, “Curtin Sarawak signs MOU with Malaysian Pepper Board,” April 3, 2018. [Online]. Available: https://news.curtin.edu.my/news/curtin-sarawak-signs-mou-with-malaysian-pepper-board/.

[109] Universiti Putra Malaysia, “Pepper Cultivation Ceremony 2018 – Pepper Farm Sarawak Research Project @ UPM Bintulu,” Sept 7, 2018. [Online]. Available: https://upm.edu.my/berita/pepper_cultivation_ceremony_2018_pepper_farm_sarawak_research_project_upm_bintulu-42061?L=en.

[110] M.H. Wong, “Diseases of Pepper (Part 1),” *Department of Agriculture Sarawak*, para. 3, May, 2010. [Online]. Available: https://doa.sarawak.gov.my/modules/web/download_show.php?id=573.

[111] Malaysian Pepper Board, “Skim Usahawan Keratan Lada,” 2019. [Online]. Available: https://www.mpb.gov.my/mpb/index.php/en/services/pepper-scheme/pepper-cutting-entrepreneurs.

[112] J. Wong, “Lower pepper production expected this year,” The Star, September 28, 2020. [Online]. Available: https://www.thestar.com.my/business/business-news/2020/09/28/lower-pepper-production-expected-this-year.

[113] J. Wong, “Malaysian Pepper Board eyes foreign investors,” *The Star*, June 22, 2020. [Online]. Available: https://www.thestar.com.my/business/business-news/2020/06/22/malaysian-pepper-board-eyes-foreign-investors.

[114] T. Nguyen, “India to spice up pepper trade,” *Vietnam Investment Review*, July 26, 2010. [Online]. Available: https://www.vir.com.vn/india-to-spice-up-pepper-trade-438.html.

[115] Noriezam, “Uggah: Govt looking at ways to help pepper farmers hit by low market price,” *Borneo Post Online*, August 17, 2020. [Online]. Available:

https://www.theborneopost.com/2020/08/17/uggah-govt-looking-at-ways-to-help-pepper-farmers-hit-by-low-market-price/.

[116] Malaysian Pepper Board, “Press Statement: MPB will resume purchases on 8/8/2019 at the same price,” July 29, 2019. [Online]. Available: https://www.mpb.gov.my/mpb/index.php/en/mpb-in-news/340-press-statement-mpb-will-resume-purchases-on-8-8-2019-at-the-same-price.

[117] U. Fischer, “Cultivating Sarawak Pepper,” *Malaysia Insights*, January 29, 2018. [Online]. Available: https://www.malaysia-insights.com/cultivating-sarawak-pepper/.

[118] Camelia, “MPB drafting regulations to protect name of Sarawak Pepper, regulate pepper trade,” *Borneo Post Online*, October 2, 2020. [Online]. Available: https://www.theborneopost.com/2020/10/02/mpb-drafting-regulations-to-protect-name-of-sarawak-pepper-regulate-pepper-trade/.

[119] Zukri, “Malaysian Pepper Board set to spice things up,” *The Malaysian Reserve*, July 8, 2020. [Online]. Available: https://themalaysianreserve.com/2020/07/08/malaysian-pepper-board-set-to-spice-things-up/.

[120] K. Vu, “Vietnam to cut black pepper farm area as global prices fall,” *Reuters*, April 24, 2018. [Online]. Available: https://www.reuters.com/article/vietnam-pepper-idUSL3N1S14CF.

[121] K. Vu, E. Davies, “Vietnam farmers warned not to expand black pepper crop to avoid glut,” *Channel News Asia*, June 9, 2021. [Online]. Available: https://www.channelnewsasia.com/news/business/vietnam-farmers-warned-not-to-expand-black-pepper-crop-to-avoid-glut-14979762.

[122] L. Riisgaard, S. Bolwig, S. Ponte, A. du Toit, N. Halberg, and F. Matose, “Integrating Poverty and Environmental Concerns into Value-chain Analysis: A Strategic Framework and Practical Guide,” *Development Policy Review*, vol. 28, no. 2, pp. 195-216, Mar, 2010.

[123] J. Earley, ‘Entering Samples using RFID,” *North Carolina Department of Transportation*, Dec, 2015, [Online]. Available: https://connect.ncdot.gov/resources/Materials/MaterialsResources/RFID%20Entering%20and%20Tagging%20Presentation.pdf.

[124] KURZ, “Digital Tamper Protection: NFC with Tamper Loop,” *Trustconcept*, [Online]. Available: https://www.trustconcept.com/en/product-demonstration/nfc-loop/?no_cache=1.

APPENDIX A. RSA EXAMPLE WITH SMALL NUMBERS

1) Randomly picked two prime numbers, *p* and *q*:

$$p = 7, \qquad q = 11$$

2) Multiply *p* and *q* to obtain *n*:

$$n = p * q = 7 * 11 = 77$$

3) Randomly picked a number for public key, *e* with the following conditions:

   a) Must be greater than 1,

   b) Lower than (p - 1) (q - 1),

   c) ***e* and** (p - 1) (q - 1) are coprime

   ∴ For simplicity, number 7 is chosen for *e*.

4) Public key (e, n) = (7, 77) is obtained and distributed to a message receiver.

5) Compute private key, *d* first:

$$E(m) = m^e (mod\ n)$$

6) Take ‘K’ (numerical representation is 10) as a simple message, *m* for encryption:

$$E(m) = 10^7 (mod\ 77)$$

$$E(m) = \mathbf{10}\ (\boldsymbol{ciphertext, c})$$

****this is a simple encryption; data packets contain more than 1 character. ****

7) The private key, *d* can be calculated by defining the following relationship with the public key, *e*:

$$de = 1 \; mod \; (p-1)\,(q-1)$$

8) Use **Euclidean Algorithm** to get the least remainder number, or 1. The placement is as follows (< > means to truncate the value):

$$(p - 1)(q - 1) \; = < (p - 1)(q - 1) \, / \, e \; > (e) + \text{remainder of the division}$$

$$60 \; = \; \mathbf{8} \, (7) + \mathbf{4}$$

Middle Process: 60 / 7 = **8** with the remainder of **4**

9) Shift the number 7 to the LHS and 4 into the bracket:

$$7 \; = \; \mathbf{1} \, (4) + \mathbf{3}$$

10) Repeat the process until the remainder of 1 is reached:

$$4 \; = \; \mathbf{1} \, (3) + \mathbf{1}$$

11) After that, use **Extended Euclidean Algorithm** to make successive substitutions, first by rearranging as follows:

$$\mathbf{1} \; = \; 4 - \mathbf{1}(3)$$

Then substituting it from 9),

$$1 \; = \; 4 - 1(\mathbf{7} - \mathbf{1}(\mathbf{4}))$$

Now simplify into this expression,

$$1 \; = \; 4 - \mathbf{1}(\mathbf{7}) + \mathbf{1}(\mathbf{4})$$

$$= \; \mathbf{2}(\mathbf{4}) - 1(7)$$

Substitute again from 8) into (4):

$$
\begin{aligned}
1 &= 2(\mathbf{60} - \mathbf{8}(\mathbf{7})) - 1(7) \\
&= \mathbf{2}(60) - \mathbf{16}(7) - 1(7) \\
&= 2(60) \mathbf{- 17}(7)
\end{aligned}
$$

12) The highlighted outcome is -17 since for the first term, 2(60) *mod* 60 is 0. IF the value is positive, then it is the private key, *d*. IF the value is negative, then it needs to be added with (*p* - 1) (*q* - 1), in this case, is 60. Therefore, *d* = -17 + 60 = 43.

13) Use formula 2.2 to decrypt the ciphertext, *c* to the original message (plaintext):

$$D(c) = c^d (mod\ n)$$

$$D(c) = 10^{43} (mod\ 77)$$

$$D(c) = \mathbf{10}$$

14) Use formula 2.3 to test the correctness even further:

$$(m^e)^d \equiv m\ (mod\ n)$$

$$(10^7)^{43} \equiv 10\ (mod\ 77)$$

$$301 \equiv 10\ (mod\ 77)$$

When the LHS value, 301 is modulo by 77, the answer is 10, which is the same answer as 10 modulo by 77. Therefore, the private key, *d* is correctly verified.

APPENDIX B. QUALITATIVE STUDY IN SARAWAK’S PEPEPR VALUE CHAIN

Interview guides:

- Make a former greeting to the chosen participant.
- Ice-breaking; introduce to the author's background, institution, and the objective of the session.
- Inform the participant that any information collected will solely use for research purposes and be kept confidential from outsiders.
- Questions can be asked by the participant during any intervals of the session.
- A concession is required from the participant to record the conversation and convert it into transcripts in either audio or text form.

Information from smallholder farmers

1. How many years of experience do you have in operating pepper plantations?

2. How big is your pepper cultivation field in acres?

3. What input materials/fertilizers/manures have you used for the pepper crops?

4. When is the harvest season for the pepper crops?

5. How long does it takes to cultivate pepper into fully ripe berries for harvest?

6. How much pepper harvests have you collected during each season or the latest season per kilo or tonne?

7. In estimation, what is your total income of pepper crops during the harvesting season?

8. What varieties of pepper have you had currently under cultivation?

9. Do you currently own, rent from landlords, or share the cultivation space among partners for the pepper plants?

10. How much is your total cost of procuring the necessary farming tools and agricultural inputs?

11. Have you ever stopped purchasing agricultural inputs and tools due to the lack of funds?

12. Have you joined any farmer or relevant associations that helps and thrives your pepper business?

13. If yes, what kind of services do they provide to their members?

14. Any improvement in the profitability of the pepper business after joining the association?

15. How many workers do you currently employ to take care of the pepper cultivation field?

16. How much is the wage for each worker per month?

17. Do you required to send harvested berries to a designated location or visited by collectors/traders periodically?

18. If yes, what transportation do you use to carry the stocks to the rendezvous point?

19. Do you think is possible to maintain one single crop, that is pepper to sustain your daily and family needs?

20. Any other crops cultivated under your care besides pepper?

21. Do you plan to assign successors to preserve continuance of the pepper cultivation?

22. If no, what is the reason for not doing so?

23. How many hours do you spend on the field per day?

24. Do you possess a bank account for managing business revenues?

25. Do you have access to any credit services?

26. If yes, can you describe the procedures prior to the approval?

27. Have you received any formal training from the extension agent?

28. What is your reliable source of information regarding the pepper economy?

29. Do you refer any daily pricing chart of pepper berries and follow the designated pricing?

30. Have you conducted any form of accounting throughout your pepper business in monthly basis?

31. Have you received any form of assistance from the government or any third-party agency?

32. What is the role of the Malaysian Pepper Board and how does it helps to your pepper business?

33. Do you plan to expand your current pepper plantation field or business operation in the coming future?

34. How many customers do you have regularly per month?

35. What is the maximum shelf-life of harvested pepper berries?

36. Do you acquire any machinery to sort and grade harvested pepper berries?

37. Any comments on how the government should take care of pepper farmers' welfares?

Common / Shared questions among pepper stakeholders

1. Who are your buyers/customers and sellers/suppliers of the pepper berries/products?

2. What are the average buying and selling prices of the pepper crops/products per kilo or tonne?

3. What are the average buying and selling amount of the pepper crops/products in kilos or tonnes?

4. What is the most difficult situation that you have encountered during the daily pepper operation?

5. Aside from the mentioned constraint, any other issues you have commonly faced in the ongoing pepper operation such as:

a) the bargaining power, b) market information, c) price instability, d) credit services, e) public infrastructures, f) marketing channels, g) extension support, h) quality control, and others

6. Are you able to supply majority of the demands or satisfy the requirements set by the buyers/customers?

7. Do you have legally binding agreement with the suppliers and buyers?

8. Do you have your own warehouse or storage facility to store the pepper berries/products?

9. How long does it takes for a batch of pepper crops/products to be cleared or sold from the warehouse or storage facility?

10. What kind of trade licenses do you require for the pepper business?

11. Do you accept any supply contracts from consistent buyers?

12. How do you process the pepper before marketed to the subsequent holders?

13. Do you consider quality over quantity for the pepper production?

14. Which bank do you normally request for the credit services?

15. Any collateral required for getting the credit services?

16. Do you receive the allocated amount in cash, cheque, or through online banking?

17. What are your thoughts in the current pepper economy in Sarawak?

18. Are you satisfied with your current position in the pepper industry of Sarawak?

19. Any comments and suggestions to improve the pepper industry of Sarawak?

20. What are the disruptions that you have to forcibly faced during the COVID-19 pandemic?

21. What methods do you use to curb and get through difficult periods?

Behavioral intention of digitalization among pepper stakeholders (optional)

On the scale of 1-5, how strong is your interest in a mobile application that helps to:

a) gather all stakeholders of Sarawak's pepper sector in a single platform.

☐ Not at all interested ☐ Not very interested ☐ Neutral ☐ Somewhat interested ☐ Very interested

b) communicate and discuss business trades via the prepared platform.

☐ Not at all interested ☐ Not very interested ☐ Neutral ☐ Somewhat interested ☐ Very interested

c) maintain regulations of digital trades under the supervision of Malaysian Pepper Board.

☐ Not at all interested ☐ Not very interested ☐ Neutral ☐ Somewhat interested ☐ Very interested

d) construct digital identities for various purposes such as:

i. Digital storefront

☐ Not at all interested ☐ Not very interested ☐ Neutral ☐ Somewhat interested ☐ Very interested

ii. Verification of genuine business

☐ Not at all interested ☐ Not very interested ☐ Neutral ☐ Somewhat interested ☐ Very interested

iii. Credit and loan application

☐ Not at all interested ☐ Not very interested ☐ Neutral ☐ Somewhat interested ☐ Very interested

iv. Extension services

☐ Not at all interested ☐ Not very interested ☐ Neutral ☐ Somewhat interested ☐ Very interested

v. e-Payment and e-Transfer portal

☐ Not at all interested ☐ Not very interested ☐ Neutral ☐ Somewhat interested ☐ Very interested

vi. Financial management tool: maintaining financial statements and audit trails

☐ Not at all interested ☐ Not very interested ☐ Neutral ☐ Somewhat interested ☐ Very interested

vii. Community forum

☐ Not at all interested ☐ Not very interested ☐ Neutral ☐ Somewhat interested ☐ Very interested

viii. Rating scale and comment section

☐ Not at all interested ☐ Not very interested ☐ Neutral ☐ Somewhat interested ☐ Very interested

ix. Product traceability using QR code technology

☐ Not at all interested ☐ Not very interested ☐ Neutral ☐ Somewhat interested ☐ Very interested

APPENDIX C. SIMULATION SCREENSHOTS

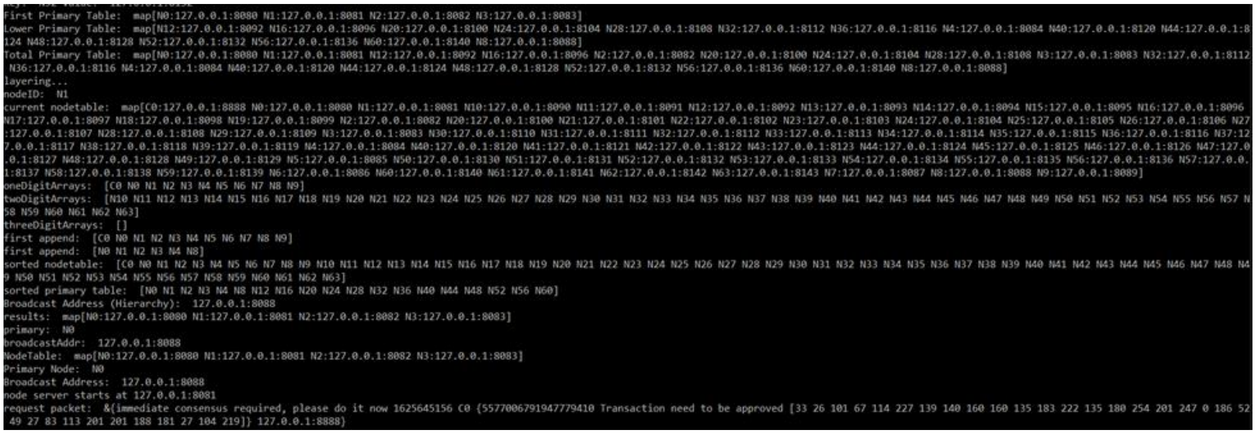


Figure C1: Layering and setting broadcast address

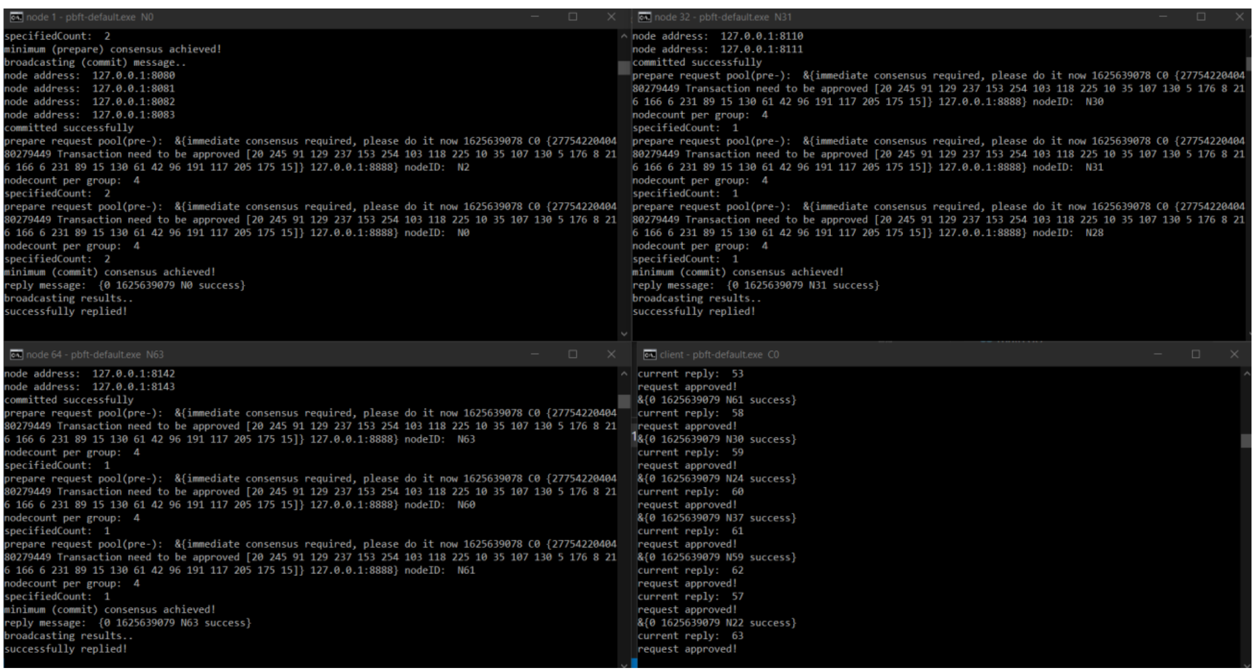


Figure C2: Command Line Interfaces (CLIs) of the Layer network operation with 64 nodes and a client node

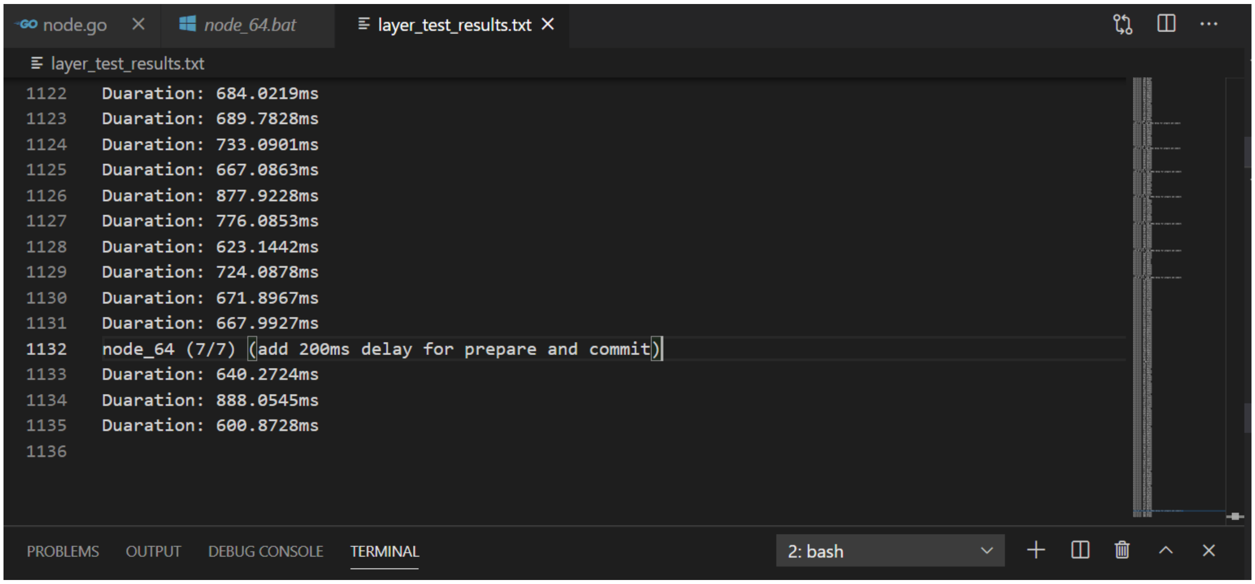


Figure C3: Data log of completion time for the Layer network structure

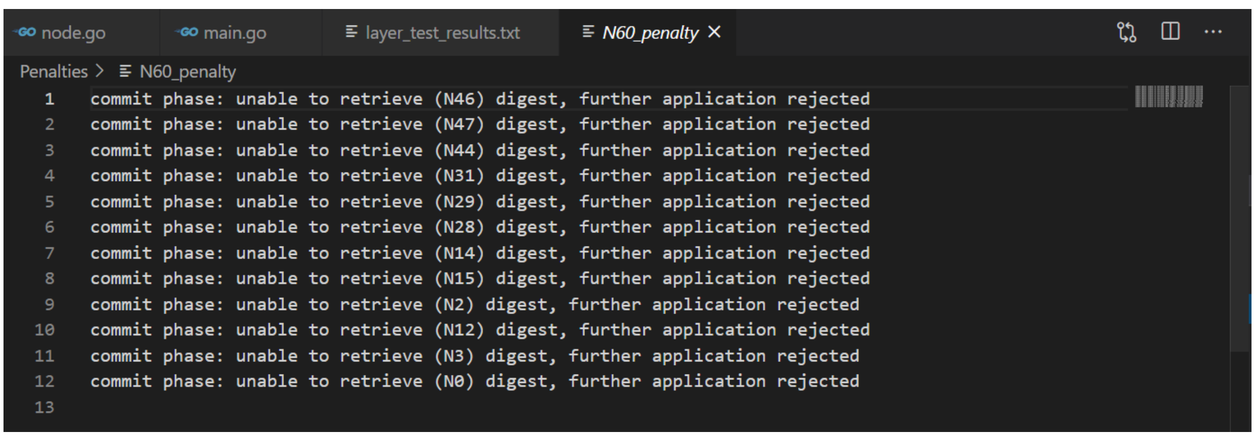


Figure C4: Data log of penalties for the Layer network structure

APPENDIX D. NOTABLE ALGORITHMS

Algorithm 1: Message Handler with Goroutines (node.go)
Input: a replica node & node address, nodeTable
Output: acquired mutual consent
begin
    for //infinite loop
        Open listening port
        Accept incoming packets, *data*
        Generate asynchronous threads with goroutines to handle incoming packets
        Use a declared *queue,* a channel data type variable to pipe *data* to handleMsg()
        Generate asynchronous threads with goroutines to handle messages based on the packet header
        for //infinite loop inside handleMsg()
            header, *payload*, *sig* := splitMsg(*data*)
            switch(*header*)
                case Request: handleRequest(*payload, sig*)
                case PrePrepare: handlePrePrepare(*payload*, *sig*)
                case Prepare: handlePrepare(*payload*, *sig*)
                case Commit: handleCommit(*payload*, *sig*)
        end for
    end for
end

Algorithm 2: Group Network Operation (group.go)
Input: a replica node, a nodetable
Output: *newNodeTable*(grouped), assigned primary node
begin
    Initialize an empty map with string to string; *newNodeTable*
    Initialize three arrays of string data type for storing keys based on digits
    Initialize a counter: *count* - when 4 is reached, reset back to 0,
    Initialize two flags: *match* - set to true if the current key-value matches the terminal *nodeID*,
                done - set to true once *newNodeTable* has filled

    for *a* := range nodeTable
        if length equals to 2 //including the word 'N', means a node
            append to an array; oneDigitKeys
        else if length equals to 3
            append to an array; twoDigitKeys

```
        else
            append to an array; threeDigitKeys
    end for

    using sort.Strings() to all arrays, then append to key array respectively

    for a := range keys // key array
        if a != "C0"
            if count is equal to 0 AND done is false
                re-initialize newNodeTable
        Divide the key-value from the sorted nodetable to keyArr and valArr respectively
        if nodeID is equal to a (current loop value)
            match assigns to true
        Increment the count counter
        if count is equal to 4
            count is reset to 0
            if match is true
                for (p := 0; p <= 3; p++)
                    newNodeTable[keyArr[p]] = valArr[p]
                    increment newNodeCount
                    set primary to the keyArr[0],
                    set done to true,
                    set match to false
                end for
        set keyArr and valArr to nil,
        set assignFlag to true
    end for
end
```

Algorithm 3: Layer Network Operation (hierarchy.go)
Input: a replica node (*nodeID*), a nodetable, and a primary nodetable
Output: *newNodeTable* (layered), assigned primary node, *broadcastAddr*
begin

```
    Initialize an empty map with string to string; newNodeTable
    Initialize an empty map with int to string; indexTotalPrimaryNode
    Initialize array variables for sorting
    Initialize three counters: count - when 4 is reached, reset back to 0,
                               indexPosition - traverse index of indexTotalPrimaryTable for
                               setting the matched primary node with a broadcast address (next
                               layer, same column of primary),
                               indexPrimary – same functionality as indexPosition but dedicated
                               for the array of sorted primary keys
```

Initialize three flags: *match* - set to true if the current key-value matches the terminal *nodeID*,
done - set to true once *newNodeTable* has filled,
assignFlag – set to true once *newNodeTable* has filled, then the next primary node will be assigned to the current primary node

```
for a := range nodeTable
        if length equals to 2 { //including the word 'N', means a node
                append to an array; oneDigitKeys
        else if length equals to 3
                append to an array; twoDigitKeys
        else
                append to an array; threeDigitKeys
end for
for a := range primaryNodeTable
        if length equals to 2 //including the word 'N', means a node
                append to an array; onePDigitKeys
        else if length equals to 3
                append to an array; twoPDigitKeys
        else
                append to an array; threePDigitKeys
end for
Using sort.Strings() to all arrays, then append to key and primary key arrays respectively

for a := range primarykeys //primary key array
        //append all primary keys to indexTotalPrimaryTable with indexPrimary as the
        increment counter
end for

for a := range keys // key array
        if a != "C0"
                if count is equal to 0 AND done is false
                        re-initialize newNodeTable
        Divide the key-value from the sorted nodetable to keyArr and valArr respectively
        if nodeID is equal to a (current loop value)
                match assigns to true
        Increment the count counter
        if count is equal to 4
                count is reset to 0
                if match is true
                        for (p := 0; p <= 3; p++)
                                newNodeTable[keyArr[p]] = valArr[p]
                                increment newNodeCount
```

set *primary* to the *keyArr[0]*,
set *done* to true,
set *match* to false
end for
if *assignFlag* is true
if *indexTotalPrimaryTable*[*indexPosition*] is equal to *nodeID*
broadcastAddr = valArr[0]
Increment *indexPosition*
set *keyArr* and *valArr* to nil,
set *assignFlag* to true
end for

set assignFlag to false,
set indexPosition to 0
end

THE END