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Mobility and Quality of Service in Wireless Multicast Infrastructure

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Abstract—This paper defines a new wireless mobility architecture with quality of service (QoS) that uses the fixed network infrastructure for group communication. The mobile core-based tree (M-CBT) architecture uses multicast to provide fast handoff and reduce network utilization costs for group communication. The M-CBT architecture can be coupled with a multicast QoS routing protocol to provide QoS for mobile communication. The Explore Best Path Message (EBPM) protocol is a probe-based dynamic distributed multicast QoS routing protocol that is designed to quickly search the network for an optimal QoS path from a joining node to the multicast tree. This paper illustrates how mobile devices using M-CBT and EBPM can participate in group communications and quickly find a QoS path as they handoff to a new network.

Index Terms—Mobility, Wireless Multicast, Multicast QoS

I. INTRODUCTION

A typical industrial environment will conduct communication between controllers, actuators and sensors on a fixed network (including wired as well as wireless devices). The recent uptake in wireless technology has brought benefits in terms of cost reductions and flexibility of usage as to how the factory floor utilizes sensors and other wireless network devices.

Wireless technology can be broadly categorised into two areas - infrastructure based and ad hoc based wireless networks. In an infrastructure based environment, a wireless device will be connected to an access point which in turn is connected to a wired backbone network. This kind of network is typically used indoors, ie. offices and factory floors. An ad hoc based network is comprised of many wireless devices forming a network among themselves without a need for any fixed network infrastructure.

An ad hoc network is a good approach if a network infrastructure is not available. However, in an industrial setting where a fixed infrastructure is available, the better approach for wireless technology implementations is one that makes use of the existing infrastructure.

In this paper, we discuss one such approach developed by us. The rest of the paper is structured as follows. Section II describes a real-time mobile sensor architecture used in a petroleum refinery. Section III discusses work done by other

researchers in the area of mobility and quality of service (QoS). Our proposed architecture is described in section IV with the results presented in section V. We conclude this paper in section VI.

II. REAL-TIME MONITORING APPLICATION

Industrial monitoring applications have been developed to display real-time data so that managers and company personnel can make informed decisions. These applications are typically used to monitor the status of industrial equipment to ensure optimum operations.

In [1], Weaver proposed a Java based Internet monitoring application where sensor data is stored in a database which can be viewed on a web browser. He developed a GUI based process flow diagram that displays the monitoring information at a petroleum refinery. Perrett in [2] developed a real-time factory monitoring application for use in an integrated circuit facility where the application will display the status of the manufacturing equipment to the user.

These monitoring applications only display collected data and do not know how the data is collected or transmitted by the underlying network. Any delay on the network will greatly impact how fast the application or database will receive the data. In a mission-critical process, any delay in data delivery can potentially have a big impact on the whole operation.

If we look at a petroleum refinery as an example, fixed wired sensors will record the condition of the equipment and environment information like temperature, pressure and flow rates in the plant. This data will be conveyed through the network to a controller either in the plant or outside the plant. With the use of wireless technology, the cost of placing sensors in the network can be greatly reduced due to reduction in cabling. An added benefit to wireless sensors is that these sensors can now be placed in areas which were inaccessible by wired sensors or their locations can be easily changed according to organisational requirements.

There has been a lot of research in ad hoc wireless sensors [3]. However, most ad hoc sensors are not mobile but monitor from a fixed location. If sensors could be mobile, it would greatly enhance monitoring in a mission critical environment.

In the case of the petroleum refinery, an employee can attach a small sensor to himself while working in the plant. As the employee moves around, this sensor can pick up any environmental data like changes in temperature or chemical content at their location. This information will be sent to the controller and corrective steps can be taken quickly during an emergency. Another example is placing mobile sensors in a petrol tanker when it leaves the refinery to ensure there are no problems during transport.

Castano et. al [4] proposed a generic ad hoc based mobile sensor architecture using bluetooth technology where the sensor would cache and stop transmission of data during handoff and resume transmission after handoff. This method ensures no packets are lost during handoff although it will cause delays in transmission during the handoff. The main weakness of ad hoc networking is short battery life due to heavy computation processes like routing. In an infrastructure based wireless network, the wireless sensors can conserve battery power since heavy computation tasks like routing will be done on the wired network. A wired medium will also be a better solution if QoS is required since it has higher bandwidth and resources compared to the wireless medium (airwaves).

Since a refinery will have multiple sensors and actuators, the use of multicast in the network would be more cost effective and efficient compared to regular unicast. Multicast is used in applications that require one-to-many, many-to-one and many-to-many communication [5]. A member of a multicast group will be connected to other members on a logical network tree. The data packet will only travel on this tree until all members receive the packet.

Although multicast can save network resources, these sensors collect mission critical data and require reliable and timely delivery of information to and from the controller. The path between the sensor and controller will need to meet QoS latency requirements for timely delivery of data.

In this paper, we will introduce a generic fixed infrastructure based wireless multicast architecture that is used in communication to and from a controller and mobile sensor equipment. These sensors can be used to monitor the environment for dangerous chemicals, operational temperature or other quantifiable environmental conditions.

III. RELATED WORK

The implementation of multicast in wireless networks has been a hot research topic. Multicast is used in macro [6], [7], [8], [9], [10] and micro [8], [11] mobility since it provides quicker handoff than a unicast based mobility scheme like mobile IP [12]. A multicast scheme is better for supporting one-to-many or many-to-one communication which is required for communication with multiple sensor nodes.

Macro-mobility multicast schemes only use multicast for connecting mobile nodes and corresponding nodes while micro-mobility multicast uses multicast to handle mobile handoffs within a domain and mobile IP for inter-domain handoffs. In this paper, we will only look at macro-mobility

multicast schemes to provide end-to-end multicast support for mobile devices with the rest of the wired network.

All of the macro-mobility multicast protocols mentioned above can easily be used to support mobile sensor node connections to the wired multicast network. If mission-critical real-time monitoring is required, the multicast tree will have to provide QoS so that the network has the resources for sensor data traffic to reach their destination successfully without causing other best-effort network traffic to fail.

A QoS routing protocol is used to find one or more feasible QoS paths based on a quantifiable QoS metric like delay. [13] lists the combinations of multiple QoS constraints that can and cannot be solved in a reasonable (polynomial) time. After finding the QoS path, the QoS routing protocol also needs to reserve resources along that path and to maintain the reservation for the duration of the QoS session [14].

In this paper, we will only look at QoS probing methods for finding a feasible QoS path. We will not look at mechanisms to reserve and maintain the QoS path. The spanning join (YAM), QoSMIC and QMRP probing algorithms have been proposed for finding a feasible path between a joining node and the multicast tree.

Carlberg and Crowcroft in [15] proposed the spanning joins (YAM) mechanism which finds one or more candidate paths from a joining router to the multicast tree. The joining router uses broadcast with reverse path forwarding to send out join messages on all available links towards the multicast tree. Once an on-tree router receives the broadcast packet, it will probe for the QoS on the reverse path taken by the broadcast. The joining router will evaluate which path contains the best QoS from the probes it receives and joins the tree using the best path it finds.

YAM wastes a lot of bandwidth and resources by searching all available paths between the joining router and multicast tree even though some or most of these paths do not provide the required QoS. The time taken for YAM to converge depends on the number of available paths to the multicast tree in the network. The more paths that are available, the longer the convergence time.

In [16], [17], Faloutsos et. al. introduced QoSMIC which is an expansion of the YAM protocol described above. QoSMIC finds a QoS path by performing a local search using a limited scoped spanning join mechanism to find an ontree router which is close to the joining node. If there are no on-tree routers close by, the joining node will send a join request to a manager on the multicast tree. This manager will choose candidate on-tree routers to start probing towards the joining router. Whether the path is joining router initiated or multicast tree initiated, the QoS probe is sent from the candidate on-tree routers to the joining node. The joining node will select the best QoS path from the received probes to join the multicast tree.

QoSMIC improves on YAM by limiting the broadcast search area to limit resource overheads. If the multicast tree is beyond the search area, the manager node can be used to choose candidate routers to initiate the probe. The only drawback is that the manager nodes address needs to be known by the

joining node for it to be contactable.

In a large network, both YAM and QoSMIC might take a long time to converge if probes are sent out at different times. The joining router has no way of knowing how long it will take for every probe to reach itself. The time a probe is sent depends on the location of the tree reached by the spanning join. The RPF used by both these protocols assume that the links are symmetrical. If the network has asymmetrical links, the convergence time might be much longer than if the network was symmetrical.

Chen and Nahrstedt's QoS-aware multicast routing (QMRP) protocol in [18] uses both single path and multiple path routing to find one or more feasible paths from a joining router to a shared multicast tree with the required QoS. The QMRP protocol starts probing for a QoS path from the joining node to the on-tree router. A joining router starts out by using single path routing but switches to multiple path routing when the probed path cannot provide the required QoS. Once a node fails the QoS check, the probe will go back one node and send out multiple path probes on every link except for the link leading to the failed node and the origin of the probe. Once the probe successfully reaches an on-tree router, it will send an ACK on the reverse path of the probe back to the joining router which will select the best path from all the returned ACK messages.

QMRP does not flood the network with as many packets as YAM or QoSMIC to find a path to the multicast tree. Unfortunately, QMRP might find itself backtracking all the way to the source to perform a multi-path search if it cannot find a QoS path at later routers. Unlike the other protocols, QMRP is only interested in finding a successful QoS path rather than the "best" QoS path from the joining node to the multicast tree.

All of the QoS routing algorithms mentioned above were designed for a fixed wired multicast network. These protocols are not optimised for speed which is an important consideration in a mobile environment. The mobile sensors cannot wait for the high convergence time taken by these algorithms after every handoff.

Another problem with the current mobile multicast protocols is that each mobile node requires one or more IP addresses. In an industrial environment where hundreds of sensors are used, the implementation of these protocols will be limited to the availability of IP addresses. A more scalable approach is required before mass implementation of mobile sensors can become a reality.

IV. MOBILE MULTICAST WITH QoS ROUTING ARCHITECTURE

We have developed a mobile multicast architecture called mobile core-based tree (M-CBT)[6], [7] that decouples the sensor node from the rest of the IP multicast architecture. M-CBT uses a bi-directional shared tree to communicate on the fixed infrastructure with all multicast group members (including other mobile nodes). The multicast tree will consist of fixed nodes (including access points) only. A mobile sensor

will be transparently attached to the multicast tree through an access point which will be used as a gateway for the mobile sensor to communicate between itself and the rest of the network.

Although M-CBT provides quick handoff, the path it uses might not be adequate for transmitting mission critical data between the mobile sensor and corresponding node (controller). We have developed the Explore Best Path Multicast (EBPM) [19] QoS routing protocol which can be used together with M-CBT for finding an optimal QoS path to the tree quickly after handoffs. The EBPM scheme is a dynamic and scalable distributed probing method that finds a QoS path based on an additive metric like latency, a multiplicative metric like reliability, a concave metric like minimum bandwidth or a combination of two metrics. For simplicity, this paper will only look at the latency metric.

The diagram in fig. 1 shows a mobile sensor joining the multicast tree in order to communicate with the controller. This architecture can be implemented in any industrial network by replacing mobile sensors with any other mobile device and the controller can be any other wired or wireless communicating device.

Sensor X will connect to access point (AP) 1 via a wireless link layer connection. In this paper, we assume that the link layer is a MAC connection although it can be any other link layer connection. The wireless sensor will send a M-CBT registration message to AP 1. This registration message will include the QoS requirement for the connection. For this example, let us assume that the end-to-end QoS delay requirement between a controller and sensor is 10 ms.

Once AP 1 receives the registration message, it will send an IGMP membership report [20] to join the multicast group

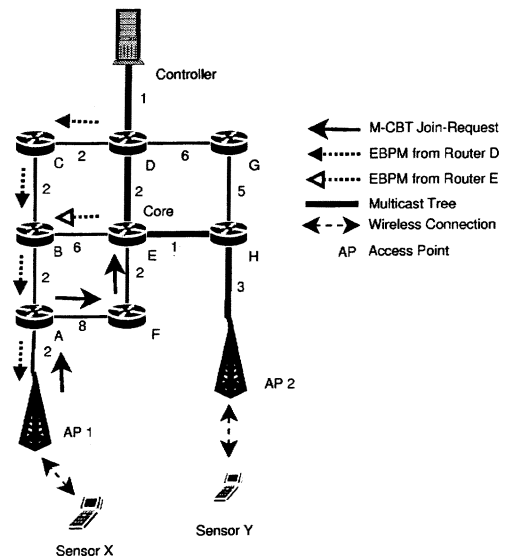


Fig. 1. A mobile sensor uses M-CBT and EBPM to find a QoS path to the multicast tree.

along with a QoS probe to the first-hop multicast router (router A). Router A will send a CBT join message with a QoS probe on the shortest path to any on-tree routers on the multicast tree.

The purpose of the probe is to collect QoS information along the shortest path from the access point to an on-tree router which is (AP 1 → router A → router F → router E). Once an on-tree router receives the join message, it will compare the collected QoS value from the probe with the required QoS. If the path taken by the join message meets the QoS requirement, the on-tree router will send an acknowledgement on the reverse path taken by the join message.

In fig. 1, the shortest path has a delay of 10 ms to router E which brings the end-to-end delay between the sensor and controller to 13 ms. Since the required end-to-end QoS delay is 10 ms, router E being the core router will multicast an EBPM Initiation message with the multicast tree latency value as a countdown timer to all on-tree routers. These on-tree routers will broadcast EBPM messages on every qualified outgoing link that is not connected to another on-tree router after the timer expires. The use of the timer means every on-tree router will send the EBPM message at the same time so that the first successful EBPM to reach the joining node would have used the optimal path.

We have also suggested in [19] two methods to reduce the number of EBPM messages by limiting the number of on-tree routers that broadcast EBPM messages depending on whether link-based routing or distance vector routing is used by the network. These methods will select only on-tree routers that are in the same two-connected component as the joining node. Only on-tree routers D and E will send EBPM messages since they have a connection to AP 1.

These EBPM messages will collect the QoS information on every path visited until they reach the joining node (access point) or until they time out. Unlike the probe sent with the join message, the EBPM messages will be evaluated by every router that receives them.

A router that receives a valid EBPM for the first time will create a reverse link pointing to the previous router that sent the EBPM. If the same router receives another valid EBPM message, it will evaluate the new EBPM and drop it if the QoS value is worse than the recorded value in the reverse link table. If the EBPM QoS value is better, the router will update the reverse link QoS value and point to the previous router that sent the new EBPM. After that, the router will update the QoS value and broadcast the new EBPM on every valid outgoing link. Thus, the network routers will build an optimal path between the joining node and multicast tree.

The EBPM message received by router B from router E will fail the QoS check since the accumulated end-to-end delay is 9 ms and router B does not have any outgoing links that won't exceed the QoS requirement. Router B will drop the EBPM message from router E.

Any EBPM message that reaches the joining node's first hop router will have found a valid QoS path. Since all of the on-tree routers initiated the EBPM probes at the same time, the first EBPM to reach the joining node will have used the

best path between the tree and the joining node. The optimum QoS path between sensor X and the controller is router D → router C → router B → router A → AP 1.

AP 1 will send a new join request message on the reverse path of the EBPM message. Each router on the reverse path will send the packet to the router on its reverse path until it reaches the on-tree router D. Router D will check the QoS requirements again and send an acknowledgement message to AP 1. The EBPM scheme is not coupled with any other QoS protocol although RSVP can be sent along with the join request, EBPM messages or join acknowledgement if it is required by the network administrator.

A. Mobile handoff

If a sensor node moves into range of another access point, the sensor node will send a registration message to the new access point. For security purposes, the new access point will authenticate the sensor node request with the current access point used by the sensor node. Fig. 2 shows the handoff process when a mobile sensor moves to a new access point.

Once the new access point receives the registration request, it will send a handoff request to the old access point. The old access point will reply with an authentication message after it verifies the handoff request is from a sensor node it knows. This authentication message will include the sensor node's credentials, multicast core address and any QoS requirements. The old access point will also forward any cached packets if there are any. After authentication, the new access point will send an unsolicited IGMP membership report informing its first hop m-router of its intention of joining the multicast tree requested by the sensor node.

If QoS is required, the routers will send a probe along with the join message to an on-tree router. If the join message followed a path that meets the required QoS, the on-tree router will send an acknowledgement message on the reverse path of the join message otherwise the on-tree router will initiate an EBPM probe to find a QoS path as described in section IV.

Once the new access point joins the multicast tree, it will

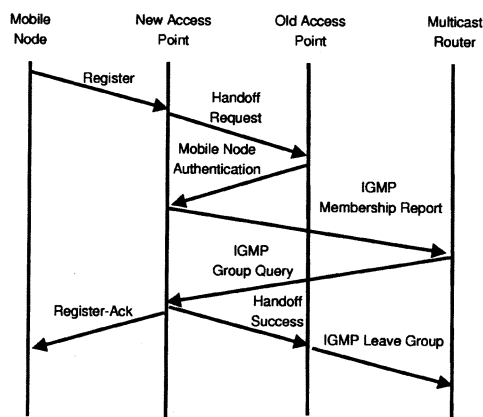


Fig. 2. Mobile sensor performing handoff to another access point

inform the old access point that the handoff was successful and send a registration acknowledgement message to the sensor node. The sensor node will update its access point address from this acknowledgement message. The old access point will leave the group if it has no other sensor nodes connected to it.

If the network has no QoS path from the multicast tree to the new access point, the new access point will inform both the sensor node and old access point that it will not accept the handoff. The sensor node can then send another registration request to the new access point, move to another access point or stay within the range of the old access point if it requires QoS.

V. RESULTS AND DISCUSSIONS

Simulations done in [8], [7] have shown that mobile multicast protocols perform faster handoffs than a unicast protocol like mobile IP. The reason for these quick handoffs is due to the inherent features of a multicast architecture like local joining, advance connection and the elimination of mobile IP problems like tunnelling, triangular routing and binding updates.

We conducted simulations to compare how quickly a mobile node can handoff when using mobile IP, Helmy's PIM-SBT protocol [8], Castelluccia's PIM-ShT protocol [9] or M-CBT. The results in table I shows the time taken for a mobile node to handoff from one access point (AP) to another. Details on how the simulations were done can be referred in [7].

The results show that all three mobile multicast protocols perform better than mobile IP. Although the simulations were done for a generic mobile network, the results should be similar for a mobile sensor network where the mobile nodes are sensors and the corresponding node is the controller. The PIM-SBT protocol provides the fastest handoff but it is not scalable since a new multicast tree has to be created for every corresponding node that wants to communicate with the mobile node. PIM-ShT and M-CBT use a shared multicast tree where many corresponding nodes can communicate with the mobile node on the same multicast tree. Both PIM-SBT and PIM-ShT do not have any handoff authentication feature whereas M-CBT and mobile IP inherently provides authentication during handoff which increase delay.

The M-CBT is the only mobile multicast protocol that provides bi-directional multicast communication. PIM-SBT and PIM-ShT use multicast for every communication directed to the mobile node and unicast for communication from the mobile node to any corresponding node. If QoS communication is required, the other protocols will need to reserve

two separate QoS paths, one for multicast traffic and one for unicast traffic while M-CBT only requires one shared QoS path.

The biggest advantage of M-CBT over the other multicast mobility architectures is that the mobile nodes do not need to use IP to communicate on the multicast tree. The access point will convert a non-IP packet into an IP packet and send it on the tree. Once the access point gets a packet for the mobile node, it will convert the IP packet into the format used by the mobile node. This allows the mobile node to perform vertical handoffs where the physical layer connection between the mobile node and the access point is technology independent. This approach also allows many mobile nodes to become part of a multicast communication without each node requiring an IP address since the IP address of the access point is used for joining and sending data on the multicast tree. The separation of wireless technology from the rest of the multicast architecture will allow all members of the tree to be mobile devices, even the corresponding node, without greatly impacting the performance of the multicast tree.

Simulations into using EBPM for finding a QoS path during handoff are still ongoing, although we did simulations for the EBPM protocol against YAM, QoS MIC and QMRP QoS routing protocols on a fixed network. We have found that EBPM has a low message complexity and faster convergence time compared to the other protocols. Fig. 3 shows the total convergence time for all QoS probes to reach the joining node. The YAM and QoS MIC protocol probes will find all the paths connecting the joining node to the multicast tree where some of these paths might not have the required QoS. The EBPM and QMRP probes will only find paths that meet the QoS requirements. The simulations were carried out on a random network that consists of 37 vertices and 40 edges connected on asymmetrical links where the joining node was incrementally moved one-hop further from the multicast tree.

If a QoS reservation is required, a QoS signalling protocol like RSVP [21] can be used to reserve QoS after EBPM finds

TABLE I
THE TIME TAKEN FOR A MOBILE NODE (MN) TO HANDOFF.

Handoff	AP1 to AP2	AP2 to AP3
Mobile IP	28.52 ms	32.01 ms
PIM-SBT	21.42 ms	22.75 ms
PIM-ShT	25.73 ms	27.01 ms
M-CBT	21.25 ms	31.53 ms

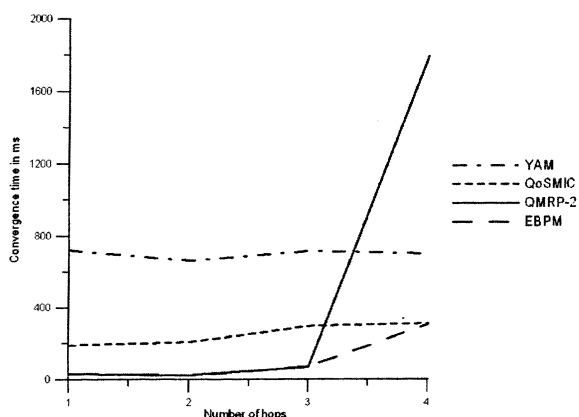


Fig. 3. Time taken for QoS probes to converge

the path or RSVP can be sent together with the EBPM probes when it is finding a QoS path between the multicast tree and access point. The reservation process will be quicker using EBPM than in a mobile IP (MRSVP) [22] architecture. In EBPM, the RSVP message reserves the QoS to the nearest branch of the multicast tree which in most cases is near the new access point. MRSVP has to perform a new resource reservation from the mobile node to the corresponding node every time the mobile node moves to a new access point. This new reservation by MRSVP will increase the handoff delay compared to M-CBT running EBPM with RSVP. If quick QoS setup is required, MRSVP can provide instantaneous QoS connections after handoff by reserving QoS from the controller to all the access points where the mobile sensor might move during the lifetime of the connection. This is not a scalable method since it creates an extra burden for routers to keep track of admission control and QoS profiles.

VI. CONCLUSION

In this paper, we propose two new protocols, M-CBT and EBPM, to be used for group communication between mobile sensors and the controller. M-CBT is a multicast mobility architecture that can provide fast handoff and is more scalable than other mobile multicast architectures. Mobile sensors can use any wireless transport protocol to connect to an access point which will use the M-CBT protocol to transparently send and receive IP data on the multicast tree.

The EBPM protocol is a distributed QoS probing mechanism that is used in conjunction with M-CBT to quickly setup a QoS path from the multicast tree to the access point. EBPM performs better in terms of message complexity and convergence time compared to other QoS multicast routing protocols. EBPM also provides faster QoS handoffs than a mobile IP scheme since it only has to find a QoS path from the access point to the multicast tree which is usually a few hops away.

The benefits of scalability, quick handoffs and quick QoS path exploration when using M-CBT with EBPM will enable mobile sensors to provide real-time monitoring over the network.

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