A NEW MULTICAST ROUTING ALGORITHM FOR ZIGBEE NETWORKS

Bilge Kartal, Radosveta Sokullu
Dept. of EEE, Ege University, Izmir, Turkey

Tapio Suihko
Technical Research Centre of Finland

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Abstract: In recent years, wireless sensor networks have become widely spread in many areas including medical applications. Some of these applications outgrow the traditional communication model applied to wireless sensor networks according to which data is flowing towards a single receiver (sink). In the case of medical data acquisition systems more then one receiver is a viable model. In this paper we discuss details on data broadcast algorithms for the 802.15.4 based ZigBee network standard and their applicability to creating sensor networks for medical data applications, focusing especially on transmitting data to multiple receivers (multicast concept). The multicast concept is not currently supported by ZigBee. So we have focused on introducing a multicast communication model and suggested a new algorithm based on ZigBee which is specifically optimized to support multiple sinks. Further on the paper describes our experiences with developing M-Bee, a multicast routing algorithm platform, using the open Microchip's ZigBee software stack.

1 INTRODUCTION

In recent years wireless sensor networks (WSNs) have become a very active research area supported both by recent advances in hardware and pressing demands for creating ubiquitous sensing environments for our future world. Simulation and experimental work is focusing on verifying and creating suitable application oriented communication models and protocols for a new wireless environment. As an example we can consider the healthcare sector. A number of wireless medical monitors are currently on the market, including electrocardiographs (EKGs), pulse oximeters, blood pressure monitors, fetus heart rate and maternal uterine monitors. Most of these devices use Bluetooth or analog Wireless Medical Telemetry Service (WMTS) bands, and several employ IEEE 802.11. However, these systems are generally designed only to "cut the cord" between the sensor worn by the patient and a bedside monitor or another nearby receiving device. In the future such systems will be built on wireless sensors and will require to be incorporated in a network, to provide collection of data from multiple patients or to transmit data to multiple receivers (doctors, nurses) in a multi-hop structure. Similar scenarios exist in fire fighting and rescuing situations. (Lorincz 2004).

In this paper we propose a new routing protocol, M-Bee, based on IEEE 802.15.4 and ZigBee, which is enhanced with multicast features. Presently the ZigBee standard supports only unicast and broadcast transmissions. In light of the existing model above each data packet will be flooded in the network until it reaches a given receiver or receivers. If multicast is introduced the flooding will be used only for establishing a multicast route and then all the packets will be transmitted over that tree reducing the amount of traffic.

From here on the paper is organized as follows: In section 2 a concise description of ZigBee is presented. In section 3 we examine related work on multicast protocols. In sections 4 and 5 we discuss the prototype architecture and the implementation details of M-Bee, including some assumptions made for the model and details on the multicast data

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transfer mechanisms. We summarize our implementation results on Microchip's PICDEM-Z hardware in section 6, and draw the conclusions in section 7.

2 ZIGBEE AND IEEE 802.15.4

ZigBee is a wireless network protocol specifically designed for low data rate sensors and control networks. There are a number of applications that can benefit from the ZigBee protocol like building automation networks, home security systems, industrial control networks, patient monitoring, remote metering etc.

ZigBee uses the IEEE 802.15.4 physical and MAC layers to provide standard-based, reliable wireless data transfer. ZigBee adds network structure, routing, and security to complete the communications suite. On top of this wireless engine, ZigBee profiles provide target applications with the interoperability and intercompatibility required to allow similar products from different manufacturers to work seamlessly. IEEE 802.15.4 provides three frequency bands for communications.

Based on IEEE 802.15.4, the ZigBee Alliance specifies the standards for the network layer and the application layer, the ZigBee device object (ZDO) and the manufacturer defined application objects.

Two types of devices are defined: Full Function Device (FFD) and Reduced Function Device (RFD). An FFD can serve as a coordinator or regulator device. It can communicate with any other devices within its transmission range. An RFD is a simple device that associates and communicates only with an FFD.

The responsibilities of the ZigBee network layer include joining/leaving a network, security, routing, discovering 1 hop neighbours and storing neighbour information. The network topology can be multi-hop so that any pair of devices can communicate with each other through the help of intermediate node.

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ZigBee allows multi-hop communications based on Ad Hoc On Demand Distance Vector (AODV) routing protocol for general multi- hop ad-hoc networks (Ergen 2004). Multicast is not included in the ZigBee Specification v1.0. (ZigBee Specification 2005). This version assumes only general broadcast, duplicate packet suppression, and unicast transmission based on AODV.

3 RELAITED WORK

Multicast routing in ad hoc networks is a very dynamic research field. Extensions to existing ad hoc routing protocols have been proposed like MAODV, based on AODV (Royer 1999) as well as new purely multicast oriented protocols have been suggested like ODMRP and ADMR (Jetcheva 2001), (Perkins 1999). Even though these protocols are suitable for mobile nodes and wireless links they are based on the IEEE 802.11 physical layer. They also include very sophisticated link repair mechanisms as they consider larger amounts of data being transferred. To be applicable for WSN, protocols have to be very light and quickly converging because of the resource limitations of the nodes both power-wise and memory-wise. An example in this respect is AODVjr (Chakeres 2002). Another new protocol is a version of ADMR called TinyADMR which includes also multicast functions and an implementation is based on TinyOS Mica motes. (Cheng 2006). To our knowledge there is no similar work based on ZigBee, specifically on its Microchip Stack. ZigBee uses a combination of AODV and Link State Routing protocols for broadcast and unicast communication only and has no multicast concept. We believe that benefits like reduction in delivery delay, less packet overhead and decreasing network traffic can be provided by introducing multicast routing in ZigBee. We have carefully examined the Adaptive Demand Driven Multicast Routing (ADMR) and TinyADMR, which suggest some very useful ideas for multicasting. ADMR allows delivery of packets from senders to receivers by routing each packet along a set of forwarding trees that are constructed on demand. Data is multicast by sending packets to group addresses rather than individual node addresses. We have also considered the ODMRP, as it relies on a forwarding mesh instead of a tree but as its packet format cannot be reduced significantly it has not been found a good candidate.

In our work we have focused on creating a multicast mechanism model which can be incorporated with the existing ZigBee standard.

4 M-BEE AND OUR PROTOTYPE ARCHITECTURE

M-Bee is a multicast routing framework built on top of ZigBee that allows multiple patients to relay data to all receivers that have registered an interest in that patient. This communication model fits with the needs of medical applications where a number of caregivers may be interested in the same patient's data.

Our multicast model is based on two major procedures: Route Discovery (RD) and Receiver Join (RJ). During the RD phase a sender node (potentially one which has data to transmit) tries to locate the receivers interested in this data and forms a route to them. This route is reinforced during the RJ phase in which each receiver declares its joining the route to the data source. After the route is established data packets are multicast only to the nodes that have joined. Thus unnecessary broadcast is much reduced and network traffic is diminished. In implementing the ROUTE-DSICOVERY and RECEIVER-JOIN procedures we have utilized the broadcast and unicast possibilities presented by ZigBee.

Our prototype realization of M-BEE is a network design consisting of one coordinator and seven client devices. We focus on the case of multiple receivers, in which data from a single node (patient) has to reach with min latency and min network traffic multiple receiver nodes (caregivers). We have implemented the M-Bee design in several layers of the ZigBee stack including the network and MAC layer. We use Microchip PICDEM-Z board as hardware and Microchip ZigBee Stack as software.

5 M-BEE MULTICAST PACKET FORMAT AND PROTOCOL OPERATION

The IEEE 802.15.4 maximum MAC frame size is 127 byte with 16 bit CRC. The maximum application payload size is 97 bytes, calculated as:

127-[MAC Header(11)+NWKHeader(8)+ APSHeader(6)+AF Header (for MSG,3)+ CRC(2)]=97

Each M-Bee multicast packet carries an 8 byte M-Bee header. The M-Bee Header fields are briefly described below:

PacketType (1 byte): Indicates whether a packet is a ROUTE-DISCOVERY, RECEIVER-JOIN or DATA message.

Group Address (1 byte): The group address of the packet.

Origin MAC Address (2 byte): According to IEEE 802.15.4 the MAC address of any node is 8 bytes but for our implementation in order to save memory space we use only 2 bytes.

Origin NWK Address (2 byte): Network address of the node.

Hop Count (1 byte): The number of hops the packet travels (used only for RECEIVER JOIN packets).

Route Cost (1 byte): Reserved for future optimization of routing criteria and performance evaluation.

According to the ZigBee routing mechanism for a packet to be sent we need a route request packet (6 bytes) and a route reply packet (8 bytes). If we have more than one receiver then we using the same mechanism we have to build a route tree for every receiver separately. So the overhead/payload is directly proportional to the number of receivers. On the other hand in the case of M-Bee it is not necessary to build a separate tree for each sender-receiver pair and thus the total overhead/payload is reduced and not directly proportional to the number of receivers. As an example let us take the case with 1 sender and 3 receivers. According to the ZigBee routing mechanism a separate process will be initiated for each of the 3 receivers with (8+6) 14 bytes packet overload, which makes 14*3=42 bytes route setup only. Additionally the same data will be sent 3 times, once for each receiver. In M-Bee the same example will need an 8 byte header Route Discovery packet and each receiver node will respond back with a Receiver Join 8 byte packet. The total for route discovery and set up requires up to 4*8=32 bytes. The normalized packet overhead is defined as the total number of all data and control packets transmitted by a node in the network (sender), divided by the total number of all data packets received across all multicast receivers.

Route Discovery Process: Route discovery process begins with the sender sending out a ROUTE-DISCOVERY packet via its M-Bee endpoint and M-Bee output cluster with broadcast address. Every node receiving this packet rebroadcasts the packet once allowing the message to propagate throughout the network. At each receiver the packet is received via the corresponding M-Bee endpoint and M-Bee input cluster. At the application layer, we use the APSDE_DATA_request primitive and its parameters for transmitting data, and APSDE_DATA_indication primitive and its parameters for receiving data.

Upon receipt of a new ROUTE-DISCOVERY packet, the node table entries are checked and refreshed. Instead of carrying the information about the sender node that originated the discovery, the previous hop and the hop count in the packet header in M-Bee we get this information using the MCPS_DATA_indication primitive parameters and then record it in the necessary node table.

Receiver Join Process: When a receiver of a group of receivers gets a ROUTE-DISCOVERY packet, it sends a RECEIVER-JOIN packet back to the original sender as a unicast message using path reversal. Election of forward path is made using the ZigBee broadcast algorithm. Path reversal unicast address is obtained at every node from the previous hop address field in the node table which was recorded during the ROUTE-DISCOVERY process.

Each intermediate node receiving a RECEIVER-JOIN packet configures itself as a forwarder for the corresponding (sender, group) pair. Once a sender receives even a single RECEIVER-JOIN, it can start broadcasting data packets for the given receiver group.

***Data Delivery Process*:** Forwarding the data along the forwarder tree, a different broadcast mechanism is needed. To create it we use a decision mechanism on top of the ZigBee broadcast communication. In the existing ZigBee broadcast communication realization a node sends the data to the upper layer only after retransmitting it. This is necessary because of the passive acknowledgement mechanism. So, on top of this existing broadcast mechanism we add a subroutine in the ZigBee network layer for multicast communication. When forwarding packets to interested receivers M-Bee multicast algorithm has to check if a node is configured as a “forwarder node” before retransmitting the packet. Non forwarding nodes, receiving a broadcast packet will drop it and won’t retransmit it. Only forwarding nodes will keep retransmitting the packet. So the packet will travel only via the route reinforced by forwarder nodes until it reaches the receivers.

When a source node and a forwarder are no longer effective at delivering packets to downstream receivers, they should stop re-broadcasting messages to avoid wasting bandwidth. For this we have suggested quite a simple routine utilizing the nwkPassiveAckTimeout and the nwkMaxBroadcast Retries value.

6 EXPERIMENTAL SETUP AND RESULTS

In order to test the multicast communication model and algorithm suggested we designed several experiments to observe its performance. Once the network was set up, packets were injected for periods of 5 seconds, at a constant data rate of 20 packet per second, followed by variable random intervals of silence. A max of 75 bytes packet payload is used. We evaluate the time for setting up a multicast tree for networks with different number of nodes and the packet delivery ratio (PDR).

Testing ROUTE-DISCOVERY process is done by observing the time spent for route establishment. This time is calculated from the moment a ROUTE-DISCOVERY packet is sent until the reception of first RECEIVER JOIN packet. As for the PDR it has been calculated in accordance with (Cheng 2006) – total number of packets received to the number of expected packets by all receivers. We test networks with different number of nodes and different numbers of receivers.

According to our results the ROUTE-DISCOVERY time for the suggested M-Bee multicast routing is short enough to allow DATA trassmission of low sample rate medical data.

The results given below show the route establishing times averages for a network of 1,2,..n hops (where n_{max} = number of nodes in the network - 1) in a 5 and 8 node network respectively. (Figure. 1 and Figure.2)

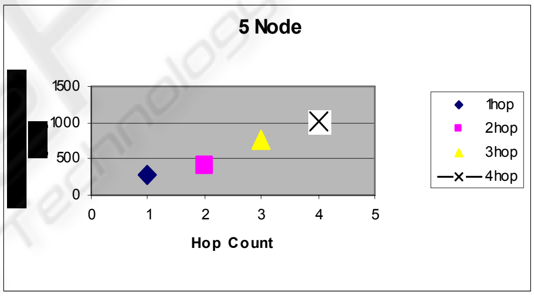

Figure 1: Average Route establishment times in a 5 node network.

Further on we especially focused on investigating the PDR as defined in the previous section. The results prove that the proposed M-Bee multicast algorithm has high reliability.

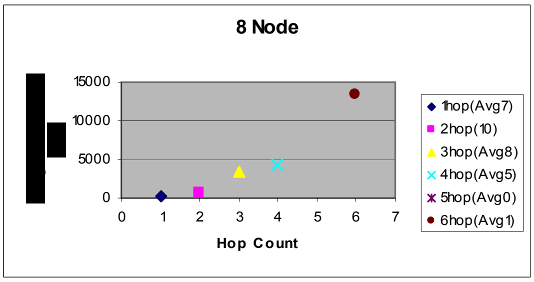

Figure 2: Average route establishment times in an 8 node network.

Figure 3 shows packet delivery ratios taken after each packet injection for the cases of 1 sender and 1, 2, 3 receivers accordingly. We can observe values as high as 0.975. Increasing the number of nodes, we still observed high reliability (average above 0.9) with only few occasions of more than 10% of the packets lost.

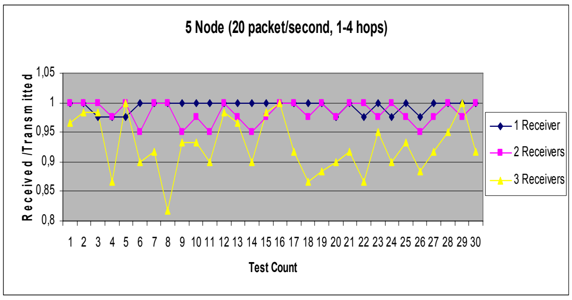

Figure 3: Effect of increasing number of receivers on packet delivery ratio.

We compare our results with those in (Cheng 2004) because those are the only published results for multicast routing in WSN known to the authors so far. The report similar values for the case with 20 packet per second and 1 sender 1 receiver and 1 sender 3 receivers. The horizontal axis in our graphics is an example run of tests where after each injection of packets in the network we wait for a random period of time before the next one.

We believe that the results from our experimental work support the thesis that ZigBee can be used for multicast routing as for example M-Bee. They also provided us with a better understanding of the implications created by real wireless communications as well as helped us define and communicate to MicroChip several problems with their software stack.

7 CONCLUSIONS

In this paper we have presented the design and implementation of a multicast communication protocol called M-Bee. We have extended the unicast and broadcast routing mechanisms provided by ZigBee with multicast features.

Our major goal is to demonstrate with a practical implementation that ZigBee can be augmented with modifications for multicast routing. Our results demonstrate that such an approach is possible but there is still significant work to be done if M-Bee multicast is to scale for larger networks. Present problems are in a great extend due to some inconsistencies with the addressing scheme in Microchip stack.

In conclusion, this paper has presented an initial exploration into the challenges of software design for some specific application scenarios for WSNs..

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