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Reliable routing using heterogeneity in wireless sensor networks

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Abstract—Health care monitoring using wireless sensor networks is limited by energy, low bandwidth and small memory storage. In this kind of networks, Packet Delivery Ratio (PDR) is often too low, so it is a challenge to support transmission reliability. In health care context, heterogeneous nodes are generally used. This paper presents a new approach to improve the transmission reliability with a new multicast routing protocol (HMR) which uses this heterogeneity. This approach exploits some powerful nodes instead of all nodes to forward packets avoiding the loss of packets and reducing the overhead. Simulation results show that this approach could be an interesting solution both in BAN (Body Area Network) and PAN (Personal Area Network).

I. INTRODUCTION

Health care monitoring is a useful technique for early detection of many symptoms and illness. As a step forward to ubiquitous monitoring, wireless sensor networks (WSN) could be an interesting solution for this kind of applications. However, wireless sensor networks (IEEE 802.15.4 [1]) do not support heavy load because they are limited by energy, short transmission range, low throughput and small memory storage. At Network layer, one solution could be multicast protocols, as multicast protocols can reduce the network load. However, existing multicast protocols in wireless networks cannot be applied directly into the health care monitoring, because some characteristics in health care monitoring are not totally similar than sensor network characteristics. Particularly, enabling a degree of mobility for both patients and doctors and having many body sensors within each patient are two important requirements in health care monitoring.

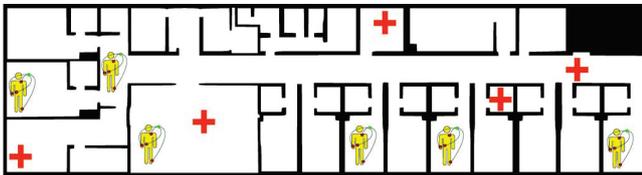


Fig. 1. Building with patients wearing sensors (yellow) and doctors (red cross) monitoring them.

Sensor networks for health care can usually be classified into Body Area Network (BAN) and Personal Area Network (PAN). In a BAN, sensors are grouped into a small area with a distance less than one meter, while in a PAN, sensors have a range of 20-30 meters. As a result, it is a challenge to present

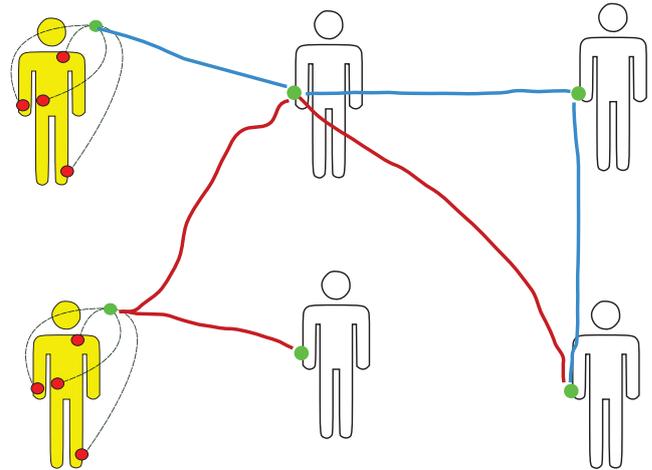


Fig. 2. Network topology: patients (yellow) wearing normal sensors (red dot) and doctors (white) routing information to receivers through powerful nodes (green dot).

a multicast routing protocol suitable for both BAN and PAN. Unlike general sensor networks, we introduce two types of nodes: powerful node and normal node. In a group of sensors, normal nodes gather medical measures and regularly send packets to their associated powerful node (also called group coordinator). Then, powerful nodes communicate between them to reach receivers. Figure 1 illustrates a building with six patients (in yellow) and five doctors (red cross). Every patient wears a powerful node and many normal nodes, doctors are equipped with a powerful node. It is important to notice that one or more doctors want to receive information updates from source nodes (such as temperature of a patient). Figure 2 shows patients (in yellow) with many normal sensors (red dots) reporting data to many receivers (in white). Powerful nodes (green dots) participate in the data forwarding process.

In this context, only powerful nodes participate to multicast routing. Based on the existing multicast routing ODMR (On-Demand Multicast Routing Protocol) [2], we present a novel multicast routing with heterogeneous nodes named HMR (Heterogeneous Multicast Routing).

HMR approach works as follows: Normal nodes in a group forward their packets to their corresponding powerful node

(only one powerful node per group). Powerful nodes act as routing attractors. If there are two possible routes between the sender (a powerful node) and the receiver (another node), the one with the highest number of powerful nodes is chosen. Moreover, the network maintenance is supported by control messages when a patient or a doctor joins to the network.

With HMR, collisions at MAC layer are reduced and PDR (Packet Delivery Ratio) at Application layer increases. Our simulation results show that the transmission reliability could be supported in health care monitoring in sensor networks.

This paper is organized as follows: related works are listed in Section II. Then a description of our HMR protocol is presented in Section III. In section IV, simulation environment and simulation results are analyzed. Finally, section V gives conclusions and perspectives.

II. RELATED WORKS

According to the survey presented in [3], many papers studied health care monitoring systems using wireless networks. Authors organize implementations according to the technology used for each network. For example, an approach includes only one radio per person for the PAN and many wired sensors inserted in clothes for the BAN. Some of the works mentioned by the authors in [3] include different radio technologies to transmit data (i.e. IEEE 802.11, Bluetooth) in each network (BAN, PAN). However, only two projects are totally based on IEEE 802.15.4 standard [1] for data exchange between a BAN and a PAN for a Health care monitoring system. Those projects consist on MEDiSN [4] and CodeBlue[5]. MEDiSN uses TinyOS and the Collect Tree Protocol (CTP) for routing. CTP is a Gradient Based routing protocol and uses Expected Transmission Count (ETX) to establish the gradient. The project CodeBlue[5] uses an adaptation of ADMR (Adaptive Demand-driven Multicast Routing protocol) for TinyOS 1.0. In those works, constantly powered devices act as Static Relay Points to support transmission reliability during the data-forwarding process.

In this work we decided not to use static position relay nodes. Nevertheless, adding these static nodes can help to generate alternative paths for forwarding packets.

Another work considering several networks is presented in [6]. It proposed a “V-table scheduling” in order to mitigate hidden terminal collisions and to coordinate the sleeping periods of nodes. Let us note that this study is not complete as only one gateway is used.

The concept of initiative determination is presented by Akyildiz in [7]. According to this concept, each node “decides” whether it participates or not in routing according to values of some parameters from different layers. In our case, a node changes its behavior (powerful, normal) according to the size of its current buffer.

An interesting paper that explains the progression from Mobile Ad-Hoc Networks (MANET) routing protocols to new protocols used in WSN is presented in [8]. Nevertheless, the proposed protocols assume that most of the nodes are static and not clustered.

In WSN nodes positions are static and those positions are randomly generated (for simulations) or constrained by available space. However it is considered that the physical distribution of nodes is uniform. In our case nodes are physically clustered and move in a small space. Mesh mechanisms can be useful in sparse topologies, but have to be tested with nodes at a small distance.

III. HETEROGENEOUS MULTICAST ROUTING (HMR)

Multicast routing could be a good candidate to reduce collision at MAC layer, because a multicast routing allows to reduce network load. There exists many multicast routing protocols designed for IEEE 802.11 networks; protocols such as: ODMR [2], ADMR [9], and PUMA (Protocol for Unified Multicasting through Announcements) [10]. In health care monitoring system, we have evaluated these multicast routing protocols using some monitoring parameters in [11]. We notice that ODMR is more suitable for this application. Here we explain ODMR because it is the basis for the proposed protocol.

A. ODMR

ODMR[2] is a mesh routing protocol supporting mobility, with Publish and Subscribe mechanisms (Soft-State). The Publish and Subscribe mechanism consists to manage the association of “patients” nodes (Publish mechanism) and of “doctor” nodes (Subscribe mechanism) in the mobile environment. ODMR periodically floods Join-Query (Publish) packets by each source (e.g. temperature sensor of a patient) in a multicast group (patient Id). In this way it forms a forwarding set of nodes or “forwarding group” for each multicast group. A receiver (a doctor) joins a group by sending a Join-Reply (Subscribe) packet. When a node receives a Join-Reply (Subscribe) packet, it determines its participation in the forwarding group according to its routing table. Only source nodes can generate Join-Query (Publish) packets, and only when there is data to transfer; otherwise it just stops generating this kind of packets and the route expires. ODMR can be implemented with a timer. If no data packet was generated when the timer expires the protocol stops flooding Join-Query packets. These packets are used for Route discovery and keep-alive mechanisms.

However, we observe that ODMR cannot reach a satisfying Packet Delivery Ratio (PDR) in health care applications, because all mobile nodes participate in multicast routing. If nodes are not heterogeneous, this causes a lot of routing control messages (packets) which causes collisions. As a result, we suggest that:

- Only the coordinator of a group can participate to multicast routing, the rest of the sensors in the same group can only forward data to their coordinator; it reduces the Publication’s flooding for nodes that are physically close.
- A coordinator is a powerful node with a high storage capacity (for example a buffer size of 200) while normal node only has a small capacity (20 packets).
- A group of sensors sticks to a patient body forming a BAN.

- Some patients and doctors are in the PAN.
- All persons are mobile.

B. HRM

In this section, we present our heterogeneous multicast routing based on ODMR. We describe our Heterogeneous Multicast Routing (HMR) by the following steps:

Step One: Determine the types of the nodes. We try to separate BAN from PAN, thus we define 2 types of nodes: powerful and normal node. At start-up every node checks the size of its buffer. If it is bigger than a predefined threshold, it will behave like a powerful node, or like a normal node otherwise. Normal nodes cannot forward a Publish request from its own group neighbors or from other groups. But it can communicate with its cluster-head. In this case a node can know whether it is or not a powerful node by looking at the difference in its data buffer capacity, which are 20 and 200 respectively. Only strong nodes participate in routing with receivers. There is only one strong node per person. There is no “election” of cluster-head because it is given by the difference in hardware capabilities, memory in this case.

Step Two: Publish propagation. We consider that in a Health Care application nodes which are physically clustered generate too many collisions if all of them are participating in routing. Thereby, only powerful nodes can forward Publish packets. Another added behavior to the “Forced Cluster Head” node is that it starts storing its own group data packets if there is no receiver (doctor) while there is available space in its buffer. It will be a powerful node, that is, a node with higher capabilities in terms of storage and battery.

Step Three: Relying Subscription. ODMR uses for all its messages a broadcast transmission. Control and data packets are sent using broadcast and even Subscribe packets can be lost. We also think that MAC layer unicast for Subscribe packets can be useful, as it will add some reliability to the reinforcing path mechanism. Because it will try to receive an ACK packet or it will try again some finite amount of times. In the original protocol, subscribe packets use broadcast at the MAC layer. A node receiving a Subscribe packet verifies if it is the destination of the packet. If it is not the destination, it does not process it anymore. Otherwise, the node processes the packet at the Network layer. In our HMR approach, Subscribe requests are sent using unicast and ACK mechanism at the MAC Layer.

IV. SIMULATION ENVIRONMENT AND SIMULATION RESULTS

The idea is to reduce the generation of routing packets in clustered nodes, as explained in paragraph III-A, in order to allow nodes with higher capabilities to handle “long distance” routing. We take the following assumptions:

- Distance based propagation 15m.
- Nodes move at pedestrian speed.
- Single channel solution.
- Heterogeneous devices (sensors vs. powerful devices).

A. Simulation environment

Table I shows simulation parameters. In our simulations we use 35 nodes, which are organized in 6 groups (patients) of 5 “Sender” sensor nodes each (30 nodes following mix of Constraint Mobility[12] and Reference Point Group Mobility model [13]) and 5 Receivers (doctors). Simulation time is set up to 1000 s, in a simulation Area of size 57x15m as a floor of a hospital. Figure 3 shows a snapshot of a topology used in simulation. Nodes with an Id greater than 29 are Receivers. The other nodes are grouped in groups of five at a small distance; among which one performs as a powerful node. Nodes are moving, and a scenario can be very different from one to another. That is why we choose the *average number of partitions* as a metric to limit the number of valid scenarios that can be used. The average number of partitions shows average number of groups linked during run time. If the value is equals to 1, it means that all nodes are reachable with the given transmission range; that is, the network is always connected. Whereas a bigger value may express that isolated groups exist (nodes are too far from other nodes and communication is impossible between them). The average number of partitions of each scenario used is lower than 1.2 for a 15m transmission range; this means that there are small intervals where some nodes are isolated and no packet transmission is possible. The majority of statistics from the mobility are based on paper [14].

TABLE I
SIMULATION PARAMETERS.

Parameter	WSN	Scenario statistics	WSN
Duration	1 000 s	tx range	15 m
Area	57x15 m^2	In body distance	0.5 m
Nodes	35	partitions	1.16
Receivers	5	mob. receivers	CM
Nodes per group	5	mob. senders	Grouped CM
Min, Max speed	(0.2, 1] m/s	total links	2362
pause time	(0, 300] s	avg. path availability	96.05%

Data packets are generated as a Constant Bit Rate (CBR) flow over UDP. We use the NS-2 simulator [15] version 2.34 with the ODMR implementation performed by Jetcheva [9] and the Constraint Mobility model implemented in Bonnmotion 2.0 [16]. We run simulations for 3 configurations:

- First Scenario: Sender nodes generate 1 packet per second, and we vary the number of receivers of each group from 1 to 5.
- Second Scenario: Sender nodes generate 1 packet every 2.5 seconds, and we vary the number of receivers of each group from 1 to 5.
- Third Scenario: Sender nodes generate from 1 packet per second to 1 packet every 10 seconds with 3 receivers in each group.

B. Simulation Results

1) *First Scenario*: Unlike existing multicast routing where all nodes forward all packets in routing, HMR allows only coordinators to participate in multicast routing. As shown

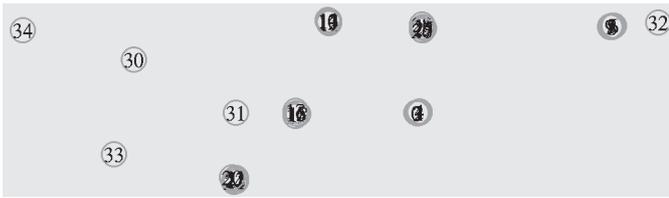


Fig. 3. Network animation showing positions of 35 simulated nodes, overlapped circles represent a patient wearing 5 sensor nodes.

in figure 4 the number of collisions reduces rapidly as a function of the number of receivers (doctors), with HMR. If the number of collisions per node and per second is about 23 when there is only one doctor in the network, with HMR, the number of collisions goes down to 11. The reduction of collisions is between 52% and 29% when compared with ODMR. Consequently, PDR reaches a maximum of 80% whereas ODMR reaches a maximum of 70% (see Figure 5). However, we observe that the PDR improvement is limited when the network load is high. This means that, when 4 or 5 doctors join the wireless sensor network, PDR could not be improved any more. When the number of Receivers grows, there are more links to maintain and more connection problems occur.

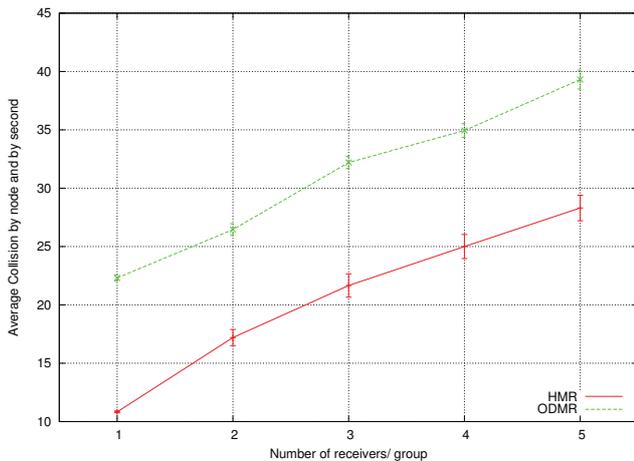


Fig. 4. Collisions. 1 packet generated each 1 second.

2) *Second Scenario:* When the generation period is 2.5 s, we can see that the overall PDR (figure 7) is higher than in the first scenario. Figure 7 shows that PDR reaches a maximum of 82%. Fewer packets are actually generated so they provoke fewer collisions (see Figure 6). The reduction of the emission rate is also reflected in control messages. In this case, the collision rate drops from 61% to 40% compared with ODMR.

3) *Third scenario:* In the third scenario, the number of packets generated varies from 1 packets per second to 1 packet all ten seconds. Figure 8 shows the reduction in term of numbers of collisions. The decrease of collisions is higher when there are more packets generated. Moreover, HMR significantly reduces collisions in any case while maintaining

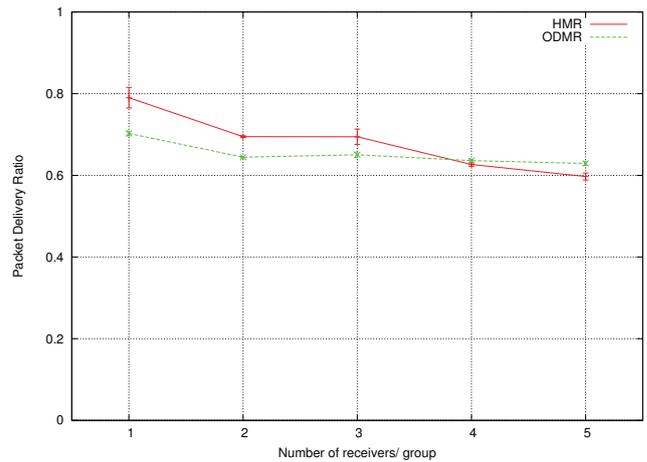


Fig. 5. PDR. 1 packet generated each 1 second.

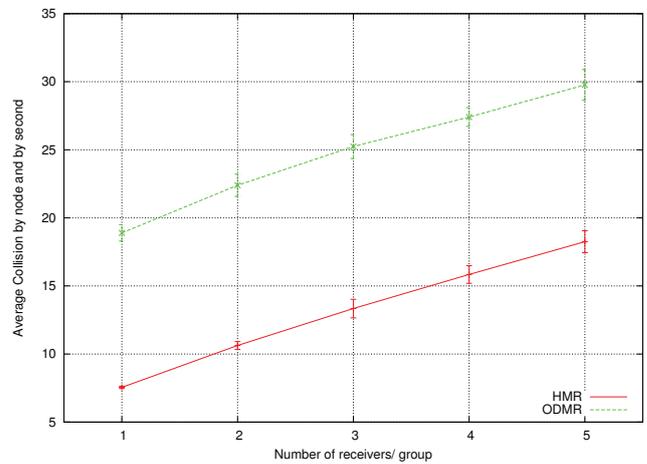


Fig. 6. Collisions. 1 packet generated each 2.5 seconds.

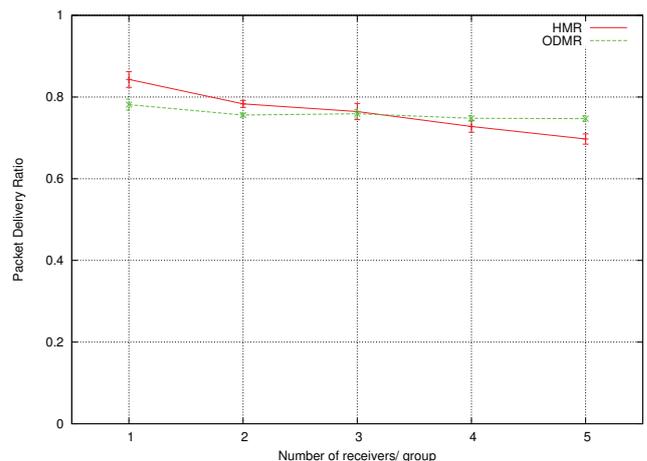


Fig. 7. PDR. 1 packet generated each 2.5 seconds.

a similar PDR (see figure 9).

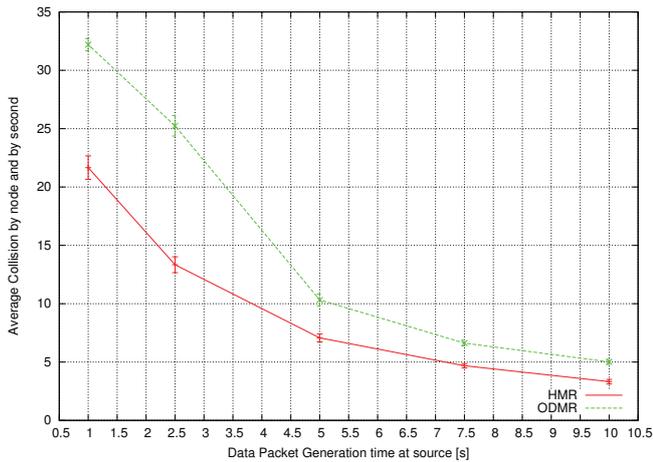


Fig. 8. Collisions. Changing data generation rate. 3 receivers/ group.

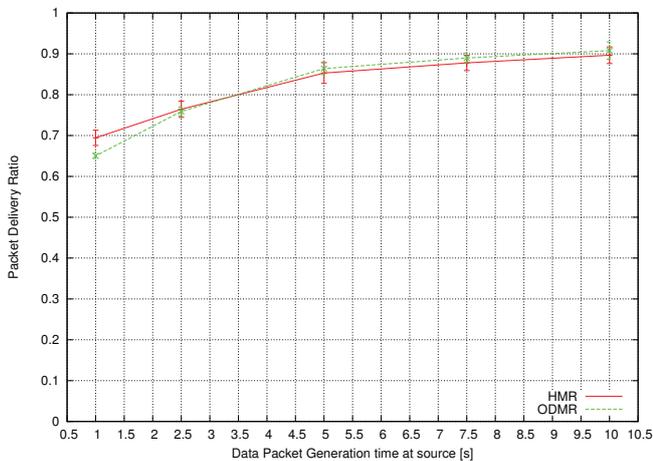


Fig. 9. PDR. Changing data generation rate. 3 receivers/ group.

C. Global analysis of results

In summary, we can see that HMR reduces collisions in all scenarios, so it is a good candidate to increase the delivery rate. We also find that the bit rate in IEEE 802.15.4 networks is very limited. When the number of receivers reaches to 4 or 5 per group, HMR no longer carries improvement.

V. CONCLUSION

In mixed wireless BAN and PAN, the transmission collision ratio is often high because of low bandwidth and small memory capacity in sensor nodes. This paper presents HMR routing protocol, an improvement of ODMR, which exploits heterogeneity to improve transmission reliability for health care applications. Without relay nodes, our HMR supports a higher Packet Delivery Ratio than some existing multicast routing protocols. In addition, two mobile models (one for patients, another for doctors) were also studied for health care monitoring applications. Thus, exploiting the heterogeneity could be an interesting approach.

Prospective works also deal with adaptive variations of HMR with respect to network density and power control management that can also be useful for this type of applications.

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