Implementation of a Data Collection Mechanism in Electronic Triage System using Wireless Sensor Devices

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***Abstract*—The electronic triage system developed by our research group is a wireless sensor network, constructed by electronic triage tags composed of vital sign sensors and ZigBee modules. The system assumes a network of hundresds of patients, simultaneously transmitting data to a remote sink. We have investigated the performance of a simple data collection mechanism in real scenarios, based on IEEE 802.15.4 in a ZigBee device like SunSPOT, and have examined some challenges in such scenarios. The data delivery ratio of 98% has been recorded while sending data equivalent to that of 100 devices in a triage tent scenario, where every device is one hop away from the sink. Adjustment of hello packet interval according to the scenarios has been observed to be an important factor. The results are found to be useful in adjusting parameters in our future work.**

***Index Terms*—Data Collection, SunSPOT, ZigBee, Wireless Sensor Networks**

I. Introduction

Triage, a process of prioritizing patients, has been introduced in emergencies like terrorist attacks, earthquakes etc in order to avoid preventable deaths. For this purpose, our research group has proposed an electronic triage system[1][2]. Electronic triage tags are attached to the patients as shown in Figure 1, and vital signs are collected via wireless sensor networks (WSNs) constructed by these tags. Each tag is composed of a sensor for monitoring vital signs and a wireless communication device, SunSPOT[3]. Patients' prioritization and periodic monitoring of patients by reliable data collection are some of the vital requirements in the electronic triage system, that makes it different from the other sensor networks. The main goal of this work is to investigate the reliability of the data collection using simple distance vector routing mechanism and examine the challenges for future works. We deal with the implementation of an ad-hoc network configuration and a simple data collection mechanism over electronic triage tags, and evaluate the performance based on real experiments.

For the data collection purpose, we have designed a simple tree routing mechanism based on IEEE 802.15.4 over the SunSPOT platform using the MAC level APIs and have evaluated the performance. In the mechanism, a flooding technique constructs the routing tree in the initial phase and periodic beaconing from the surrounding nodes maintains the neighbor nodes. A hop-by-hop collection mechanism[4] is then performed in each subtree for collecting sensed data of all nodes in the subtree to their sink node.

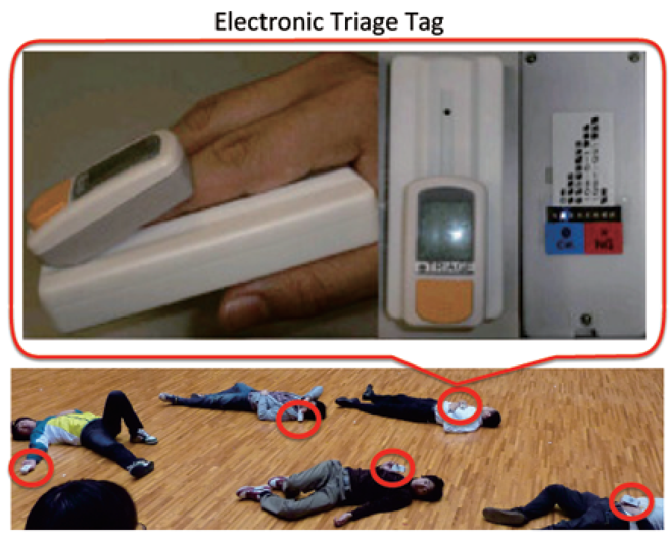

Fig. 1. Patients Wearing Electronic Triage Tags

We have implemented the mechanism and evaluated its performance through real experiments by considering various topology patterns and situations in the electronic triage scenario and have observed some challenges. We have examined the data delivery in a triage tent scenario assumed to have 100 patients by using 10 sensor devices. Conducting experiment with 100 devices is difficult due to lack of real devices and difficulty in preparation of experiments, therefore we have simulated the scenario by applying stress over 10 devices.The data delivery ratio of 98% has been recorded while sending data equivalent to that of 100 devices. Moreover, adjustment of the interval of control packets (hello packets) according to the node density has been observed to be an important factor.

II. Related Work

Various data collection protocols have been proposed for WSNs. Direct transmission is a simple approach for data collection, but it deteriorates the network lifetime by consuming large transmission power. LEACH[5] forms clusters in a self organizing manner, where each cluster head collects the data from nodes in its cluster and sends the result to the sink. However, if the cluster head is far away from the sensors, they might expend excessive energy in communication. SDAP[4] uses a probabilistic grouping technique to dynamically partition the nodes in a tree topology into multiple logical groups of similar sizes. A hop-by-hop aggregation is performed in each group to generate a group aggregate. Ref.[6] introduces a shortcut tree routing in ZigBee network by using the neighbor table. Source nodes compare all neighbor nodes within transmission range to find a node which has the smallest tree level for transmitting data packets. PEGASIS[7] constructs a chain topology not only to gather data efficiently but also to save energy consumption. However, PEGASIS needs a global knowledge of all nodes and results in excessive delay for nodes at the end of the chain which are farther away from the leader node. SPEED[8] also achieves real-time communication by considering geographical positions of nodes.

In this paper, we implement a simple data collection mechanism in the IEEE 802.15.4 based MAC implementation over the SunSPOT platform, and evaluate its performance. The mechanism is based on simple tree routing that collects the data periodically and forwards it to another node.

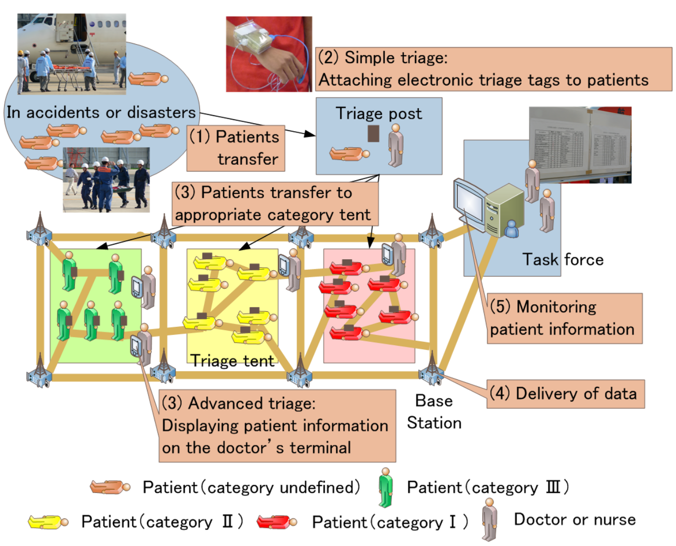

Fig. 2. Overview of Electronic Triage System

III. Electronic Triage System

Mass casualty events like fire, terrorist attacks are expected to bring a large number of affected patients. The AID-N[9] project, developed at John Hopkins University, is an example of such networks. One of the most urgent problems at the scene is overwhelming number of patients that must be monitored and tracked. The automation of these tasks could greatly increase the quality of patient care, and deliver patients to the hospital. Manually tallying and sorting patients are time consuming and prone to human error. The concept of electronic triage has been implemented that makes things more systematic and convenient. Our research group has been developing an electronic triage system in wireless ad-hoc networks as shown in Figure 2. We have developed an *electronic triage tag* composed of a ZigBee module and a sensor to sense vital signs. The system provides estimation of positions and monitoring of vital signs by constructing wireless networks among the tags.

TABLE I
Traffic in Electronic Triage Scenario

	Packet Type	Rate
Electronic Triage Tag	Hello	10 bytes/sec
	Sensing Data	(20 – 50) bytes/sec
	Localization	16n bytes per 10 seconds
		n = # of neighbor nodes

Traffic in the electronic triage system is shown in Table I. Each triage tag generates traffic from minimum (30 + 16n) bytes to (60 + 16n) bytes per second. Here, n is the number of neighbors. The hello packet includes the *node id*, and the *hop count* to the sink. The 20 bytes sensing data includes *normal* data such as, the *node id*, *timestamp*, *heart-beat rate*, *respiratory rate* and the level of SpO_2 in blood, while 50 bytes data(*wave* data) includes the granularity of vital signs for serious patients. The localization packet includes the *node id* and the *timestamp* for each neighbor node.

IV. Simple Data Collection Mechanism

The purpose of data collection in the electronic triage scenarios is periodic monitoring of patients' vital signs. The essential requirements are to construct routes from each node to the sink and to maintain those routes to cope up with the mobility of nodes. Similar to distance vector routing, a simple tree routing algorithm has been implemented to deal with the native transmission of the packets. In the initial phase, the mechanism constructs a routing tree from the sink based on flooding. Each node chooses a neighbor node as the next hop node if the hop counts to the destination is the minimum among its neighbors. For the mobility of nodes, each node maintains its neighbor node table by periodic beaconing of messages among neighbors.

In this mechanism, a node buffers the data sent from the other sensor nodes periodically, and forwards it to the parent node closest to the sink. The nodes distinguish a data packet from a beacon message by determining the broadcast transmission and unicast transmission. In case of a data packet, a node takes out the data from the data payload and stores it in its buffer. Then, the node forwards the content of the buffer to its closest parent and clears the buffer. The node uses the broadcast packet in order to maintain the neighbor

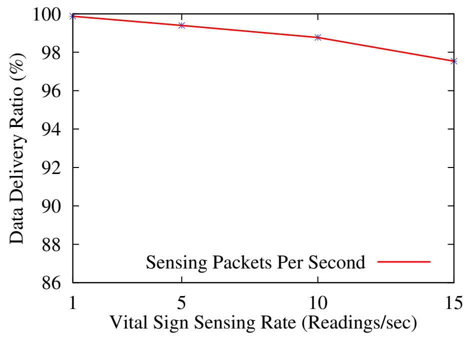

Fig. 3. Normal Data Sensor Reading

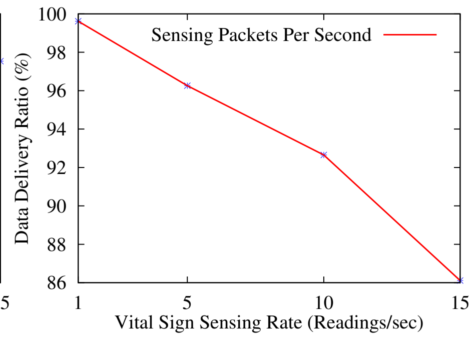

Fig. 4. Wave Data Sensor Reading

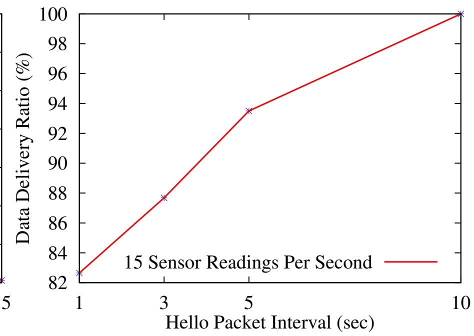

Fig. 5. Update Interval vs Delivery Ratio

node table. The node sends its sensor reading (every second) and the localization packet (every 5 seconds) separately.

The mechanism implements APIs of Mac Common Part Sublayer (MCPS) such as *mcpsDataIndication()* and *mcpsDataRequest()* for receiving and sending packets respectively. The APIS, *mlmeReset()*, *mlmeSet()*, *mlmeStart()*, *mlmeRxEnable()* of Mac Layer Management Entity (MLME) have been implemented to get access to the MAC Layer.

V. Experimental Environment

We have implemented the simple data collection on SunSPOT with wireless communication capability based on IEEE 802.15.4. The IEEE 802.15.4 employs various mechanisms to improve the probability of successful data transmission. CSMA-CA mechanism allows to wait for a random period each time a device wishes to transmit. If the channel is busy, the device waits for another random period before trying to access the channel again. Each transmit will try 5 times before giving up with a CHANNEL_ACCESS_FAILURE. Another mechanism is the frame acknowledgement. If the sender does not receive an acknowledgement after some period, it assumes that the transmission was unsuccessful and retries the transmission for 4 more times.

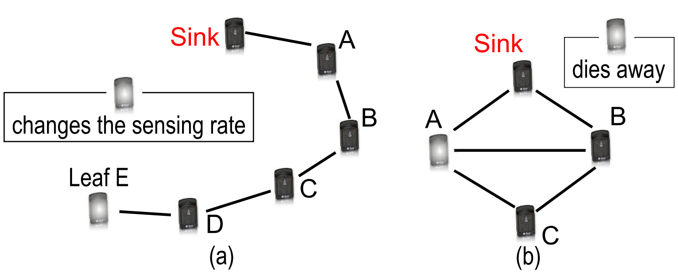

Fig. 6. (a) Outdoor (Chain) (b) Outdoor (Tree)

VI. Experimental Scenarios and Results

A. Experimental Scenarios

The patients with serious injuries are placed in the triage tents. Since, patients are incapable to move inside the tent, we can simulate a star topology where each node is connected to the sink by a single hop, and study the effect of the congestion centered at the sink. This scenario will be described as a *triage tent scenario*.

An *outdoor scenario* is the scenario outside the triage tent. We assume the patients with minor injuries outside the triage tents, are capable to move. Addition and deletion of the nodes are also frequently expected. It is clear that nodes are connected to the sink through multiple hops in contrast to the previous scenario. We consider a chain and a tree-like scenario as shown in Figure 6.

B. Results

1) Triage Tent Scenario: Figure 3 indicates the result recorded when the sensing rate of the *normal* node changes by 1, 5, 10 and 15 readings/sec. The delivery ratio of 98% has been recorded at 10 readings/sec simulated by using 10 nodes, assuming a sensor network of about 100 patients(assuming every patient senses at 1 reading/sec). In another experiment, we have changed the sensing rate of serious nodes sensing *wave* data. Figure 4 shows that the delivery ratio of 92% has been recorded at 10 readings/sec. A larger packet causes the interference from the neighboring nodes to last for the longer time. The experimental result concludes that increase in the size of the packet affects the delivery ratio in comparison to the previous result.

In Figure 5, we have studied the effect of variable hello packet interval (1,3,5,10 seconds) over the delivery ratio. The sensors sense the *wave* data at the rate of 15 readings/sec. It shows the delivery ratio increases with increase in the hello packet interval. It is mainly due to the medium being less congested during the hello packet interval of 10 seconds than in 1 second. Almost 100% of the packets have been successfully delivered to the sink at 10 seconds, while it is only 83% at 1 second. The neighbor table can be less frequently updated when the network is less mobile. Therefore, a longer hello packet interval can be considered better in this scenario.

2) Outdoor Scenario: Figure 7 shows the effect of multiple hops over the delivery ratio in chain scenario. We have performed an experiment with a single sink and 5 nodes(Figure 6(a)). The leaf E acts as a serious patient that senses the vital signs at the rate of 1, 5, 10, 15 readings/sec. The delivery ratio

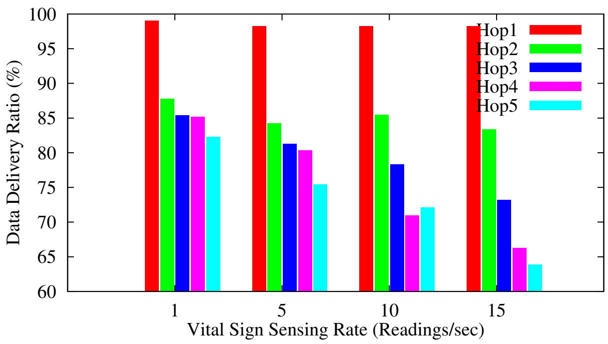

Fig. 7. Variable Sensing Rate at the Leaf Node

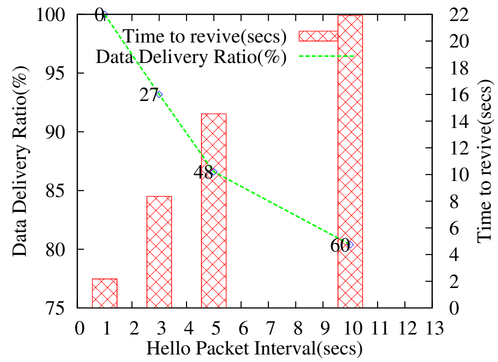

Fig. 8. Robustness (0,27,48,60 = # of Lost Packets)

of leaf E while sensing the reading at 1 reading/sec has been recorded about 83%, while that of C and D record about 85%. C and D receive more interference at higher sensing rate of leaf E (15 reading/sec), failing to deliver its own data. Low delivery ratios of 74%, 65% and 63% have been recorded at C, D and E respectively. From the results, we have observed that there is a need of packet prioritizing mechanism, that prioritizes serious nodes like E.

Figure 8 shows the effect of the hello packet interval over the delivery ratio in the outdoor scenario(Figure 6(b)). In this experiment, we study the robustness of the mechanism by deleting A when C is routing via A. Here, all nodes sense the vital sign at 5 readings/sec. The delivery ratio of C over the hello packet interval of 1,3,5,10 secs has been presented in Figure 8. There is high tendency of a node not being able to detect its neighbor in a congested environment. At 5 seconds, data of C is supposed to get delivered within 10 seconds failing 25 readings (5 readings/sec×5secs) at most. But, the result shows that it took around 15 seconds failing 48 readings causing *burst* loss. This occurs when the first hello packet of B gets lost taking 5 more seconds to broadcast the second hello packet. We can conclude that the shorter hello packet interval is favourable in the mobile scenario.

C. Discussions

From the results of triage tent and outdoor scenarios, it is clear that the interval of the hello packet has huge impact over the delivery ratio. A longer hello packet interval is effective in triage tent of less mobility, while a shorter interval is considered suitable in a mobile outdoor scenario. Dynamic adjustment of hello packet intervals can bring better performance according to the scenarios.

In a chain-like outdoor scenario, interference from the neighbor nodes and existence of hidden nodes interfere the packet delivery ratio of serious nodes like leaf E, degrading its performance. There is a need of a packet prioritization mechanism for these serious nodes. Requesting the upstream nodes to slow down their forward rate can improve the performance. Since the hop-distance from the sink has found to affect the delivery ratio, nodes can increase the frequency of retransmission with respect to the hop-distance.

VII. Summary and Future Work

Our electronic triage system assumes a network of hundreds of patients, simultaneously transmitting data to a remote sink. We have investigated a simple data collection mechanism in real scenarios based on IEEE 802.15.4 in a ZigBee device called SunSPOT, and evaluated its performance through stress tests assuming triage scenarios along with the observation of some challenges. We have examined that 98% of data has been delivered in a triage tent scenario assumed to have 100 patients by applying stress over 10 sensor devices. Moreover, adjustment of the hello packet interval according to the scenarios has been observed to be an important factor. Based on the observations, we are planning to add efficient features such as packet prioritization and dynamic adjustment of the hello packet interval.

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