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Proposed a new Algorithm for real-time applications in Routing of Wireless Sensor Networks

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***Abstract*—Many wireless sensor network applications must resolve the inherent conflict between energy efficient communication and the need to achieve desired quality of service such as end-to-end communication delay. To address this challenge, we propose a new protocol which tries to resolve the finding a trade off between lifetime of the network and real-timeness based on application. In the proposed protocol, at first, network graph constructed under effect of two coefficients. Each of these coefficients represents the importance of real-timeness or lifetime of the network. If one coefficient increased the other one will be decreased consequently. Moreover, for improving real-timeness we use EDF policy in each node to reduce miss ratio of packets. In the best condition of real-timeness of the network, the proposed protocol has been compared with the famous protocols for WSN which are classified under real-time protocols. The simulation results suggest remarkable improvement for the proposed protocol in comparison with other existing protocols.**

Keywords-Real-time; Life time; Power Consumption; Bellman-Ford algorithm; Wireless Sensor Networks;

I. INTRODUCTION

Wireless Sensor Networks (WSNs) generally consist of a large number of low-cost, low-power, multifunctional sensor nodes that are small in size and communicate over short distances [1]. Their structure and characteristics depend on their electronic, mechanical and communication limitations but also on application-specific requirements. In WSNs, sensors are generally deployed randomly in the field of interest; however, there are certain applications which provide some guidelines and insights, leading to the construction of an optimal architecture in terms of network infrastructure limitations and application-specific requirements.

One of the major and probably most important challenges in the design of WSNs is the fact that energy resources are significantly more limited than in wired networks [1][2]. Recharging or replacing the battery of the sensors in the network may be difficult or impossible, causing severe limitations in the communication and processing time between all sensors in the network.

Another issue in WSN design is delay guarantee. Many WSN applications require real-time communication. For example, a surveillance system needs to alert authorities of an intruder within a few seconds of detection [3]. Similarly, a fire-fighter may rely on timely temperature updates to remain aware of current fire conditions [4]. Supporting real-time communication in WSNs is very challenging. First, WSNs have lossy links that are greatly affected by environmental factors [5][6]. As a result, communication delays are highly unpredictable. Second, many WSN applications (e.g., border surveillance) must operate for months without wired power supplies. Therefore, WSNs must meet the delay requirements at minimum energy cost. Finally, due to the resource constraints of WSN platforms, a WSN protocol should introduce minimal overhead in terms of communication and energy consumption and use only a fraction of the available memory for its state.

The primary real-time requirement is to guarantee bounded end-to-end delays or at least statistical delay bounds. Many approaches have dealt with providing delay bounds in a multi-hop sensor network. This has been basically achieved by means of Medium Access Control (MAC) protocols such as LEACH [7], D-MAC [8], and DB-MAC [9], which guarantee that every node gains medium access rights within a bounded time interval. Other solutions have targeted the Network Layer protocols to support real-time communications, such as SPEED [10]. A brief description of these protocols, showing their advantages and limitations, is presented in Section II.

Although a lot of protocols are proposed which are power-aware or real-time, few of them consider both the energy consumption and end-to-end delay together. Moreover, all of them taking into consideration application-specific requirements. Our proposed protocol is a real-time power-aware protocol which is not limited to a specific application. It, depends on the application, is adjustable to be delay or power aware or both of them. Simulation results show that its end-to-end delay and life-time is much better than some well-known algorithms such as SPEED and RAP [16].

The rest of this paper is organized as follows: in Section 2 a literature survey is presented. In Section 3 we explain our design goal. In Section 4 our algorithm is clarified. Section 5 presents the simulation results and Section 6 provides some conclusions.

II. RELATED WORK

Power-aware routing has been investigated in several previous works. For example, Singh et al. propose five power-based routing metrics that can be used to minimize power consumption or extend system lifetime [18]. Several power-aware protocols have been proposed to maximize network lifetime [19][20]. Power-aware routing has been implemented on real wireless network platforms. Gomez and Campbell provide theoretical analysis showing that allowing each node to dynamically adjusting its transmission power leads to improved capacity and energy-efficiency over the case when all nodes use a common transmission power. Unlike our protocol, none of the above power-aware routing protocols is designed to support real-time communication.

Supporting real-time communications in wireless sensor networks has recently attracted many research efforts. As we have mentioned before, real-time mechanisms are typically implemented in the MAC sub layer and network layer of the communication stack.

Real-time support in MAC protocols generally rely on:

Scheduled-based access protocols inspired by TDMA (*Time Division Multiple Access*) such as LEACH [7], which consists of dividing the sensor network into several adjacent clusters and applying TDMA within each cluster. A randomly elected sensor node has to manage the medium access within a given cluster. Inter-cluster communications are made with CDMA protocols to avoid interference between adjacent clusters. While LEACH offers a good support for real-time communications thanks to the TDMA paradigm, it suffers from the scalability problem, since the maximum number of nodes within a cluster is limited (to eight [12]).

Improved *contention-based* protocols inspired by CSMA/CA, such as DB-MAC [9], uses a dynamic priority assignment correlated to the time waiting to transmit a packet, thereby reducing the latency to access the medium. The DMAC protocol is another solution providing real-time guarantees in wireless sensor networks, by using active/sleep duty cycles. DMAC is based on a data gathering tree, which must be constructed before starting the communication. Then, DMAC performs synchronized assignments of time slots to different nodes, in such a manner that the transmit state of a node coincides with the receive mode of a parent node. Real-time performance is improved by avoiding the data forwarding interruption problem in a multi-hop network [9]. However, this approach completely relies on a hierarchical data gathering tree topology, an assumption that is not always practical in mesh sensor networks.

On the other hand, research trends on the Network Layer have dealt with defining real-time location-based routing protocols to meet soft timing requirements in WSNs. For instance, SPEED [10] is an adaptive real-time geographic routing protocol aiming to reduce the end-to-end deadline miss ratio in sensor networks. The SPEED protocol supposes that end-to-end deadlines are proportional to the distance from the source to the destination, and thus provides soft real-time guarantees by maintaining a uniform delivery speed in the network using feedback control.

In addition to the academic research efforts, the IEEE 802.15 Working Group (WG) and ZigBee Alliance [13] have been working closely to specify an entire new communication protocol stack for Low-Rate Private Area Networks (LRWPAN).

The IEEE 802.15 WG has recently proposed the new IEEE 802.15.4 standard [14], which is intended to fulfill the requirements of LR-WPAN with relaxed need for data rate, but with more care on power consumption in order to save energy.

The standard specifies the physical layer and the MAC sub layer, which provides several medium access schemes with an emphasis on improving the real-time performance by means of time slot allocations, and power management, by means of customized active/sleep duty cycles. The ZigBee alliance aims to specify IEEE 802.15.5-compatible upper layers of the protocol stack, namely the ZigBee routing protocol at the Network Layer.

SWAN [15] uses feedback information from the MAC layer to regulate the transmission rate of non-real-time TCP traffic in order to sustain real-time UDP traffic. RAP [16] uses velocity monotonic scheduling to prioritize real-time traffic and enforces such prioritization through a differentiated MAC Layer. Woo and Culler [17] proposed an adaptive MAC layer rate control to achieve fairness among nodes with different distances to the base station. All of these algorithms work well by locally degrading a certain portion of the traffic. However, this kind of local MAC layer adaptation cannot handle long-term congestion where routing assistance is necessary to divert traffic away from any hotspot.

RPAR [11] protocol targets real-time applications and at the same time tries to optimize power consumption, constantly regulating the transmission power. This approach is, however, affected by anomalous behavior in heavy traffic conditions, which tends to favor network congestion. The reason for this behavior is that, when a node is congested, due to high contention, it has to undergo a large number of retries before transmitting a packet correctly, due to high collision probability. Hence, RPAR increases the transmission power, worsening the situation. In addition to this problem, it has to be highlighted that energy saving is limited, as nodes never go to sleep.

III. Design Goals

Our design is inspired by the observation that unlike wired networks, where the delay is independent from the physical distance between the source and destination, in multi-hop wireless sensor networks, the end-to-end delay depends on not only single hop delay, but also on the distance a packet travels.

In view of this, the key design of the proposed algorithm is to support a soft real-time communication service through the path with minimum delay across the sensor network, so that end-to-end delay is proportional to congestion of nodes between source and destination.

We use the Loop-free Bellman–Ford algorithm to find the path with minimum traffic load between source and destination. In each node we use *Earliest Deadline First* (EDF) scheduling algorithm to send the packet with earliest deadline before other packets in the node's queue. Also we use a prioritized MAC, like RAP [16].

Our protocol satisfies the following design objectives:

1. Stateless Architecture: The physical limitations of sensor networks, such as large scale, high failure rate, and constrained memory capacity necessitate a stateless approach. Our protocol only maintains immediate neighbor information. It does not require a routing table as in DSDV nor per-destination states as in AODV. Thus, its memory requirements are minimal.
2. Soft Real-Time: Sensor networks are commonly used to monitor and control the physical world. Our protocol finds the path with minimum delay across the sensor network to meet the requirement of real-time applications such as disaster and emergency surveillance in sensor networks.
3. QoS Routing and Congestion Management: Most reactive routing protocols can find routes that avoid network hot spots during the route acquisition phase. Such protocols work well when traffic patterns do not fluctuate during a session. However, these protocols are less successful when congestion patterns change rapidly compared to the session lifetime. When a route becomes congested, such protocols either suffer from a delay, or initiate another round of route discovery. As a solution, our protocol uses Loop-free Bellman–Ford algorithm to re-route packets around large-delay links with minimum control overhead.
4. Traffic Load Balancing: In sensor networks, the bandwidth and energy are scarce resources compared to a wired network. Hence it is valuable to utilize several simultaneous paths to carry packets from the source to the destination. Our protocol uses non-deterministic forwarding to balance each flow among multiple concurrent routes.
5. Localized Behavior: Pure localized algorithms are those in which any action invoked by a node should not affect the system as a whole. In algorithms such as AODV, DSR and TORA, this is not the case. In these protocols a node uses flooding to discover new paths. In sensor networks where thousands of nodes communicate with each other, broadcast storms may result in significant power consumption and possibly a network meltdown. To avoid this, only delay changes will be sent to neighbors.

IV. THE PROPOSED PROTOCOL

In this section we will introduce our proposed protocol in details.

The proposed protocol has two coefficients α and β which specify the importance of power consumption and real-timeness respectively. If we want to reduce delay, we should consume more power and vice versa. So the sum of α and β is assumed equal to one. If α increases, β will decrease and if β rises, α will go smaller.

The proposed protocol maintains a desired delivery delay across sensor networks by selecting the path with minimum delay and EDF packet scheduling policy.

For finding the path with desired delay and power (αβ), we use Loop-free Bellman-Ford algorithm. Bellman-Ford is in its basic structure very similar to Dijkstra algorithm, but instead of greedily selecting the minimum-weight node not yet processed to relax, it simply relaxes *all* the edges, and does this |V| − 1 times, where |V| is the number of vertices in the graph. Bellman–Ford runs in $O(|V|\cdot|E|)$ time, where $|V|$ and $|E|$ are the number of vertices and edges respectively, but as said before, the destination of all packets is the sink so Bellman-Ford runs in $O(|E|)$ for each node.

For starting the protocol, sink broadcasts a packet which contains its remained energy and a time stamp for calculating the delay between sink and other nodes. Each node has a routing table which has four fields: *ID, Cost of Energy, Cost of Delay* and *Total Cost*. Inasmuch as number of neighbors of each node is different, so memory consumption of each node depends to its neighbor's nodes. It means that this is a scalable algorithm and we can use it large scale WSNs. After receiving the packet, the node will update its routing table and will broadcast the packet to its neighbors. We will describe routing table fields' bellow.

For forwarding a sensing data to the sink, each node uses the Total Cost amount from its routing table. The node which has the smallest Total Cost will be the next hop that the packet will be sent. The Total Cost is obtained from following formula:

$$Total\ Cost = \left(\alpha \times \left(\frac{1}{Costof\ Energy}\right)\right) + (\beta \times Cost\ of\ Delay) \quad (1)$$

Where α and β are set by application. Cost of Delay is the smallest amount of time which is necessary to deliver a packet to sink. This delay is the sum of queue delay of nodes and propagation delay between nodes and sink. The repetitions allow minimum delay to accurately propagate throughout the graph, since in the absence of negative cycles the path with minimum delay can only visit each node at most once. Unlike the greedy approach, which depends on certain structural assumptions derived from positive weights, this straightforward approach extends to the general case. Cost of Delay is calculated from following formula:

$$Cost\ of\ Delay_i = Cost\ of\ Delay_i + Cost\ of\ Delay_{i\ to\ i\text{-}1} \quad (2)$$

Where $Cost\ of\ Delay_{i-1}$ is the smallest delay between node *i-1* and sink, and $Cost\ of\ Delay_{i\ to\ i\text{-}1}$ is the amount of time which is required to transfer a data packet to node *i-1*.

For calculating the Total Cost, we need to obtain Cost of Energy too. Since dimension of Cost of Delay is time, we need the dimension of Cost of Energy be time too. Suppose that each node knows its residual energy. In addition, it could obtain distance between itself and each of its neighbors too. So, from following formula, the node could calculate the amount of time which it has energy to send a data packet to one of its neighbors,

$$Energy_{Packet} = \left(Energy_{Elec} + Energy_{Amp} \times d^2\right) \times Packet\_Size \quad (3)$$

Where in according to, $Energy_{Elec}$= 50 nJ/bit and $Energy_{Amp}$=10 pJ/bit/m^2. We mentioned that one of the fields in routing table of each node is Cost of Energy. This parameter which its dimension is time, is calculated from following formula:

$$Cost\ of\ Energy_i = min\left\{\left(\frac{Energy_{res}}{Energy_{Packet} \times \lambda}\right), Cost\ of\ Energy_{i-1}\right\} \quad (4)$$

Where $\boldsymbol{\lambda}$ is traffic rate and Cost of $Energy_{i-1}$ is the amount of time that each of neighbors has enough energy to transfer a data packet to the sink. So the node i could calculate the path life-time which is the amount of time that it could send a data packet to sink from a path. The proposed protocol chooses the largest Cost of Energy from its routing table to use the path which has nodes with more residual energy. If the residual energy of one of the neighbors reduces, its Cost of Energy will be updated and as a result the relaying node will not select that node as a next hop. It would lead to balancing of residual energy of nodes in the network and consequently more life-time for the network.

For selecting the next hop to forward a data packet to, the proposed protocol chooses the node with smallest Total Cost in its table. Since the larger Cost of Energy is more suitable for us, for having smaller Total Cost we reverse the Cost of Energy. So in the formula (1), the larger Cost of Energy results Smaller Total Cost.

We use single hop delay as the metric to approximate the load of a node. In a scarce bandwidth environment, we cannot afford to use probing packets to estimate the single hop delay. Instead we use the data packets passing this node to perform this measurement. Delay is measured at the sender, which timestamps the packet entering the network output queue and calculates the round trip single hop delay for this packet when receiving the ACK. At the receiver side, the duration for processing an ACK is put into the ACK packet. The single-trip time is calculated by subtracting receiver side processing time from the round trip delay experienced by the sender. We compute the current delay estimation by combining the newly measured delay with previous delays via the exponential weighted moving average (EWMA) [14]. We argue that this delay estimation is a better metric than average queue size for representing the congestion level of the wireless network, because the shared media nature of the wireless network allows the network to be congested even if queue sizes are small.

If a node has heavy load then its single hop delay will be increased and by the Bellman-Ford algorithm the load will be balanced and the other node around the heavy load node will route the traffic. So traffic load and energy consumption will be balanced and the network life time will increase.

A key component of real-time communication architectures is the packet scheduling policy which determines the order in which incoming packets at a node are forwarded to an outgoing link. In existing wireless sensor networks, packets are typically forwarded in FCFS order. FCFS scheduling does not work well in real-time networks where packets have different end-to-end deadlines. Instead, competing packets should be prioritized based on their local urgency. In the context of sensor networks, packet scheduling should be deadline-aware. Deadline-aware means that a packet's priority should relate to its deadline. The shorter the deadline, the higher the packet priority should be.

Each packet is assigned a priority based on its requested deadline and queued at the network layer when there are multiple outstanding packets. Several options are available for implementing priority queues. One approach is to insert all packets into a single queue ordered by priority. When the queue is full, higher priority incoming packets overwrite lower priority ones. The benefit of this solution is that it accurately reflects the order of requested velocities, and allows all packets to share the same buffer regardless of their priority. The approach, however, requires implementing a data structure whose insertion time, in the worst case, grows logarithmically with the number of packets.

To limit the queue insertion overhead, another approach currently used in our simulation is to maintain multiple FIFO queues each corresponding to a fixed priority level. Each priority corresponds to a range of requested velocities. A packet is first mapped to a priority, and then inserted into the FIFO queue that corresponds to its priority. This approach is more efficient because no ordering needs to be performed for every incoming packet. The per-packet overhead is logarithmic only in the number of priority levels, not the number packets. To further reduce overhead, after a packet has been inserted in a priority queue, its requested deadline and priority is not updated until it reaches the next node.

Local prioritization at each individual node is not sufficient in wireless networks because packets from different senders can compete against each other for a shared radio communication channel. To enforce packet priorities, MAC protocols should provide distributed prioritization on packets from different nodes. Extensions (e.g., [15][16]) of the IEEE 802.11 wireless LAN protocol [17] have been investigated to provide distributed prioritization. Recently EDCF has been specified in the proposed 802.11e standard to provide different transmission priorities [18].

In this paper we implemented two extensions proposed by Aad and Castelluccia [19]. We modified two components of the standard 802.11 implementation: the initial wait time after the channel becomes idle, and the backoff window increase function. These mechanisms are chosen because they introduce minimal overhead and can be ported to light-weight CSMA/CA protocols [20] that are more suitable to sensor networks than 802.11. The detailed description and analysis of these mechanisms are available in [19].

V. Performance Evaluation

In this section we use Castalia to simulate the performance of proposed RACE algorithm.

Castalia is a Wireless Sensor Network (WSN) simulator based on the OMNet++ platform. This software provides a high fidelity simulation for wireless communication with detailed propagation, radio and MAC layers. Table II describes the detailed setup for our simulator. The communication parameters are mostly chosen in reference to the Berkeley Mote [17] specification.

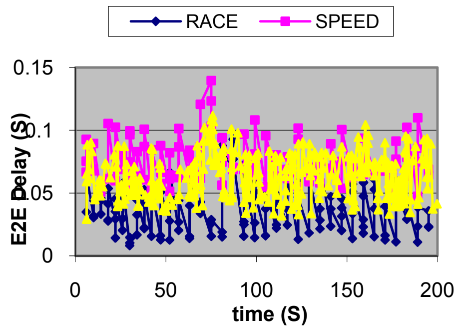
There are two typical traffic patterns in sensor networks: a base station pattern and a peer-to-peer pattern.

TABLE 1 SIMULATION SETTINGS

Routing Protocol	SPEED, RAP, Proposed Protocol
Propagation model	TWO-RAY
Bandwidth	200Kb/s
Payload size	40 Byte
TERRAIN	(200m, 200m)
Node number	100
Node placement	Uniform
Radio Range	40m

In our evaluation, we use a base station scenario, where 8 nodes, randomly chosen from the left side of the terrain, send data to the base station at the middle of the right side of the terrain. The average hop count between the node and base station is about 8~9 hops. Each node generates flow with a rate of 1 packet/second. To create congestion, at time 80 seconds, we create a flow between two randomly chosen nodes in the middle of the terrain. This flow then disappears at time 150 seconds into the run. In order to evaluate the end-to-end delay we increase the rate of this flow step by step from 10 to 90 packets/second over several simulations.

Fig. 3 plot shows the end-to-end delay.



End-to-end delay

The trend line of the above figure shown in fig. 4.

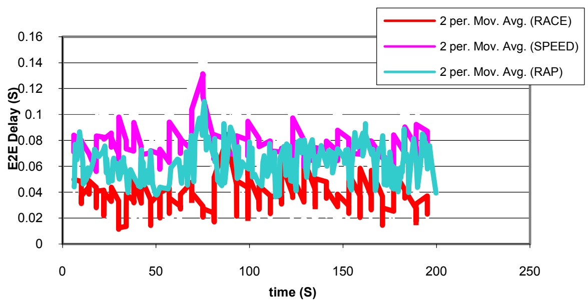


Figure 4. Trend line of end-to-end delay

As we can see, RACE reduces the average end-to-end delay by 30%~40% in the face of heavy congestion in comparison to the other algorithms considered.

Fig. 5 plot shows the miss ratio under different congestion and with different deadline. As we can see, RACE reduces the average miss ratio by 30%~40% in comparison to the other algorithms considered.

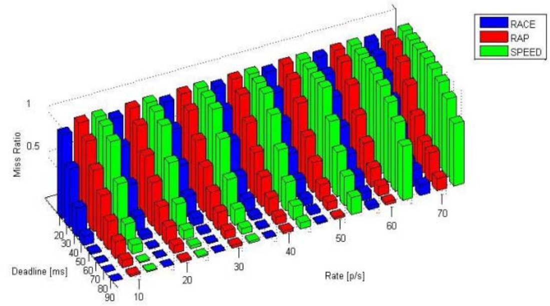


Figure 5: Miss ratio under different congestion and with different deadline

VI. CONCLUSION

Real-time communication is a critical service for future sensor networks to provide distributed micro-sensing in physical environments. We present RACE, new real-time communication architecture for large-scale sensor networks. RACE provides convenient, high-level query and event services for distributed micro-sensing applications. We use Bellman-Ford algorithm for finding a route from each source to sink with minimum delay. Weight of algorithm is propagation delay plus queuing delay plus contention delay. So we will balance load and energy consumption of network and life time of network will be increased. Also we present EDF as scheduling policy for priority queue in each node and we use prioritized MAC.

This combination of routing protocol and scheduling policy decreases 30%~40% the average end-to-end delay and the average miss ratio of RACE according to SPEED and RAP protocols.

REFERENCES

[1] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, Wireless sensor networks: a survey, Computer Networks 38 (2002) 393–422.

[2] S. Slijepcevic, M. Potkonjak, Power efficient organization of wireless sensor networks, in: Proc. IEEE Int. Conf. on Communications, Helsinki, Finland, 2001, pp. 472–476.

[3] T. He, P. A. Vicaire, T. Yan, L. Luo, L. Gu, G. Zhou, R. Stoleru, Q. Cao, J. A. Stankovic, and T. Abdelzaher, "Achieving real-time target tracking using wireless sensor networks." in RTAS'06.

[4] C. Lu, G. Xing, O. Chipara, C.-L. Fok, and S. Bhattacharya, "A spatiotemporal query service for mobile users in sensor networks," in ICDCS '05, 2005.

[5] J. Zhao and R. Govindan, "Understanding packet delivery performance in dense wireless sensor networks," in SenSys '03, 2003, pp. 1–13.

[6] A. Cerpa, J. Wong, L. Kuang, M. Potkonjak, and D. Estrin, "Statistical model of lossy links in wireless sensor networks," in IPSN '05, 2005.

[7] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, Energy-Efficient Communication Protocols for Wireless Microsensor Networks, In Proc. of the Hawaii International Conference on Systems Sciences, Jan. 2000.

[8] G. Lu, B. Krishnamachari, C.S. Raghavendra, An Adaptive Energy Efficient and Low-Latency MAC for Data Gathering in Wireless Sensor Networks, In Proc. of the 18th International Parallel and Distributed Processing Symposium, pp. 224, Apr. 2004.

[9] G. D. Bacco et al., A MAC Protocol for Deal-Bounded Applications in Wireless Sensor Networks, In Proc. of Third Annual Mediterranean Ad Hoc Networking Workshop, June 27-30, 2004.

[10] T. He, J. Stankovic, C. Lu, and T. Abdelzaher, SPEED: A Real-Time Routing Protocol for Sensor Networks, in Proc. of ICDCS'03,May 2003, pp. 46–55.

[11] O. Chipara, Z. He, G. Xing, Q. Chen, X. Wang, C. Lu, J. Stankovic, T. Abdelzaher, "Real-time Power-Aware Routing in Sensor Networks", 14th IEEE Internat. Workshop on Quality of Service, 2006, pp. 83-92.

[12] W. Ye, J. Heidemann, Medium Access Control in Wireless Sensor Networks, Wireless Sensor Networks, pp. 73-91, ISBN:1-4020-7883-8, Kluwer Academic Publishers, 2004.

[13] ZigBeeAlliance, http://www.caba.org/standard/zigbee.html.

[14] LAN-MAN Standards Committee of the IEEE Computer Society, Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LRWPANs), IEEE, 2003.

[15] G. S. Ahn, A. T. Campbell, A. Veres and L.H. Sun. SWAN: Service Differentiation in Stateless Wireless Ad Hoc Networks, In Proc. IEEE INFOCOM'2002, June 2002.

[16] C. Lu, B. M. Blum, T. F. Abdelzaher, J. A. Stankovic, and T. He. RAP: A Real-Time Communication Architecture for Large-Scale Wireless Sensor Networks, In IEEE RTAS 2002, September 2002.

[17] A. Woo and D. Culler. A Transmission Control Scheme for Media Access in Sensor Networks, In IEEE MobiCOM 2001, July 2001.

[18] S. Singh, M. Woo, and C. S. Raghavendra, "Power-aware routing in mobile ad hoc networks," in MOBICOM '98, 1998.

[19] Q. Li, J. Aslam, and D. Rus, "Online power-aware routing in wireless ad-hoc networks," in MOBICOM '01, 2001.

[20] Q. Li, J. Aslam, and D. Rus, "Online power-aware routing in wireless ad-hoc networks," in MOBICOM '01, 2001.