Management of Real Time Constraints in Sensor Networks

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***Abstract*—The scope of this paper is to compare existing techniques proposed to manage real time (RT) communications in wireless sensor networks. MAC, network or cross layer solutions are presented and discussed in order to draw up a global view of system designs. Identifying drawbacks of existing works allows drawing future directions concerning QoS guaranteeing data delivery under time constraints.**

***Index Terms*—wireless sensor networks, real time issues, deadline, prioritized queues, real time routing, scheduler**

I. RT CHALLENGE

Quality of service (QoS) in terms of real time aspects needs to be proposed in sensor networks especially when they concern solutions addressing critical applications. Most domain applications such as battlefield surveillance, disaster and emergency detection, deal with real time constraints. Compared with solutions in traditional distributed systems, approaches for sensor networks need to be adapted because of the following reasons. First, guaranteeing that communications meet real time constraints should not compromise other critical system properties, especially energy efficiency, robustness and scalability. Second, limited resources, computational or characterizing network (as bandwidth) impose supplementary restrictions.

We intend to compare techniques proposed by some representative existing work in regard to three classes of solutions. The first concerns approaches exclusively involved at MAC layer. The second addresses routing at network layer. The third tackles scheduling approaches either at MAC layer or at network layer or both, known as cross-layer techniques. Our comparative analysis completes the state of art proposed in [1], is more precise than the survey on QoS in [2] and extends the real time addressed only in routing made in [3]. Moreover, specific comparison points help identifying rapidly differences between approaches. These are: the type of real time solution (soft or hard), scalability, the type of the MAC layer (involving the portability issue), the routing mechanism, the node addressing and the scheduling policy (prioritization, delaying). We have chosen two projects for each class of solutions: SWAN [4] and I-EDF [5] for MAC layer, RAP [6] and JiTS [7] for scheduling and SPEED [8] and RPAR [9] for routing.

We briefly present in the next section each of the mentioned approaches, section 3 gives comparative analysis for each class, while interesting directions to be exploited are discussed in section 4. The last section concludes this analysis.

II. RT APPROACHES

A. MAC layer

I-EDF [5] is a MAC protocol based on priorities, addressing hard real time traffic. It is built upon three principles: cellular network structure, a modified MAC layer and a deterministic EDF[1]-type scheduling. The network organization in cells is meant to avoid contentions. Nodes are synchronized over a same frame and organize themselves into adjacent cells. Inter-cell communication is based on a synchronized TDMA scheme, while inner-cell communication is supported by earliest deadline first (EDF) schedule.

SWAN [4] addresses soft real time communication through service differentiation, at MAC level. SWAN model is stateless (no flow state is conserved in nodes). Meanwhile, the flow state is maintained in the flow itself, in the packet header. SWAN deals with two types of flow: real time and best-effort. The real time constraints are preserved using three principles: control the real time session admission rate, delay the best effort flow and notify when congestion appears. Mainly, SWAN restricts best effort traffic in order to yield the necessary bandwidth required to support real time traffic.

The summary of these MAC approaches in regard to the management of the real time issue, the intervention layer, the routing protocol, its advantages and drawbacks, as well as the simulation tool is given in table I.

	I-EDF	SWAN
RT management	avoid contentions and collisions	delay the best-effort traffic to accelerate the real time
layer	MAC	MAC
routing protocol	multi-hop	AODV or IP
advantages	hard real time, no packet loss	stateless, delaying approach
drawbacks	modified MAC layer and specific network structure	modified MAC layer
simulator	NS-2	NS-2

TABLE I
SUMMARY OF RT MAC LAYER APPROACHES

[1]Earliest Deadline First

B. Network layer

SPEED [8] is a stateless protocol which supports a soft real time communication service with a desired delivery speed across the network. The next hop is determined on the basis of the packet speed and its geographical position according to destination. The selection of the next hop is done in four stages. First, SNGF, a GF[2]-like routing protocol, considers, out of the neighbor nodes those which bring closer the packet to destination. Second, packet speed is computed for each of the previously retained nodes. The speed is calculated by dividing the advance in distance from the next hop by the estimated delay to forward a packet to the next hop. Third, among all candidate nodes, those which assure a speed to the packet greater than a referential speed are considered for the last step, which chooses the node having the greatest speed. If there is no neighbor which can support the desired speed, packets are dropped.

RPAR [9] tackles energy issue in the routing policy to support real time communication. RPAR assumes that a soft deadline is assigned to each packet by the application, specifying the desired bound on the end-to-end delay of the packet. The main idea is to combine optimization of both energy consumption and message latency: tight deadline packets are routed with lower latency by increasing transmission power; conversely, lax deadline packets may be routed with lower transmission power allowing energy saving. This approach is similar to SPEED in assigning speed to packets depending on the packet's deadline. Moreover, RPAR integrates energy metric in the choice of the neighbor which meets speed requirement. Unlike SPEED, RPAR protocol operates at an adaptive transmission power level.

The summary of these routing approaches is given in table II.

	SPEED	RPAR
RT management	keep desired speed between nodes	keep dynamic speed based on adaptive transmission power
layer	network	network
routing protocol	DV based	GF
advantages	stateless, void avoidance, best effort MAC-layer	power-aware, void avoidance, no periodic exchange
drawbacks	greedy algorithm+ GF	not adapted to congestion
simulator	GloMoSim	Prowler

TABLE II
SUMMARY RT ROUTING APPROACHES

C. Scheduling

RAP [6] is built up of a key-component, the packet scheduler, which assigns priority to packets depending on its requested velocity. Assuming that each sensor knows its location, velocity can be computed locally on the basis of Euclidean distance to destination and the packet's deadline. A packet with higher requested velocity is assigned a higher priority (each priority corresponding to a range of requested velocities). Priority queues are implemented at network level. RAP maintains multiple FIFO queues each corresponding to a fixed priority level. The packet having received a specific priority (based on its requested velocity) is inserted to the FIFO queue corresponding to its priority. The MAC layer is prioritized in order to include packet priorities.

JiTS [7] uses a different technique based on packet delay, according to the distribution of the slack-time (which is the available time before the deadline expires) across hops. Assuming that every packet knows its deadline, a delay per packet is computed as the difference between its deadline and the time globally spent in packet transmission, averaged by the number of hops. Time spent in end-to-end communication is estimated using the time spent in the MAC queue and the real transmission time on the medium. The delay time is used to order the waiting queue. It may be either static, fixed at the initiator of the packet, or dynamic, recomputed upon arrival at each intermediate node. The dynamic approach adjusts the requested velocity of the packet depending on its actual progress. Delaying packets assures that periods of congestion are avoided (by anticipating deadlines), while respecting real time policy.

The summary of these scheduling approaches is given in table III.

	RAP	JiTS
RT management	assign priorities to packets depending on their deadline and distance to destination	packet delaying, slack-time assigned depending on deadline
layer	MAC and network	MAC
routing protocol	GF + greedy	LS
advantages	"local emergency" of packets	avoids latency due to contention and congestion
drawbacks	localization-aware and modified MAC	small precision in the hop time estimation
simulator	GloMoSim	NS-2

TABLE III
SUMMARY OF RT SCHEDULING APPROACHES

III. COMPARATIVE ANALYSIS

We make a synthesis of different real time approaches, regarding its class (hard or soft), its scalability, the type of MAC layer involved, the type of node addressing (IP-based, ID-based, query-based, geographic, attribute-based), the type of the routing protocol, the scheduling policy (priority on packets). MAC approaches are summarized in table IV, scheduling approaches in table V and routing approaches in table VI.

Experimental results for these approaches are difficult to compare for two main reasons. First, implementation tools are not homogeneous (GloMoSim, Prowler, NS-2). Second, and most important, parameters of the simulation environment (radio transmission range, network bandwidth, data packet size, packet deadline, packet rate) are rarely similar.

[2]Geographic Forwarding

	SWAN	I-EDF
RT	soft	hard
scalability	good	moderate
MAC layer	DCF	EDF + frame sharing
node addressing	IP	ID
routing	AODV/IP	multi-hop
scheduling policy	-	EDF/no contention

TABLE IV
COMPARATIVE ANALYSIS FOR RT MAC APPROACHES

	RAP	JiTS
RT	soft	soft
scalability	good	good
MAC layer	prioritized MAC	CSMA/CA
node addressing	geographic	IP/geographic
routing	GF	SP/GF
scheduling policy	VMS	delay

SP = Shortest Path
VMS = Velocity Monotonic Scheduling

TABLE V
COMPARATIVE ANALYSIS FOR RT SCHEDULING APPROACHES

IV. RT MANAGEMENT SYNTHESIS

We identify major design information which needs to be exploited in order to offer real time guarantees. As far as the mechanisms involved, new directions are still open. Obviously, evaluation metrics are commonly accepted and listed here.

A. Exploited information

Real time communications can be taken into account in wireless sensor networks, based on different information, which we group in four categories:

- time,
- distance and localization,
- contextual,
- derived.

Time is essential and is available under different forms: the deadline imposed by the application, the time estimation of a hop communication (either between direct neighbors or for end-to-end paths). The former should be correlated with the network size (in order to be able to respect deadlines) while the latter is generally estimated by time measure of one hop communication or in a predictive manner.

Distance and localization information is mainly computed based on the number of hops or on Euclidean distance (using GPS technology or estimation of signal power). These mainly provide geographic knowledge about the next hop in regard to destination.

Contextual information concerns the environment (medium, density, etc.) or nodes. We identify, for example, the packet size, the available bandwidth, the node energy and also the presence of congestions, or contentions.

Derived information is extracted from previous information and from application parameters. For example, velocity in SPEED or RAP depends on time and Euclidean distance, or the slack-time in JiTS depends on deadline.

	SPEED	RPAR
RT	soft	soft
scalability	good	good
MAC layer	DCF/ MAC best effort	DCF without RTS/CTS
node addressing	geographic	geographic
routing	SNGF (optimized GF)	geographic
scheduling policy	none	velocity-based

TABLE VI
COMPARATIVE ANALYSIS FOR RT ROUTING APPROACHES

B. Issues and challenges in RT approaches

Definitely, real time frameworks designed to assure that packets transmitted in wireless sensor networks meet deadlines are oriented towards soft solutions. Hard real time systems, assuming that the arrival of a message after its deadline is system failure, are difficult to achieve. Logically, only MAC layer modifications are suitable for hard real time service, but diminish scalability and portability.

Two main issues concern real time communication in sensor networks: information recovery for real time management and data delivery.

Information is generally local, which allows high network scalability. Delivery deadlines are time constraints; therefore, estimation of communication time between neighbor sensor pairs is required in order to choose the best route meeting the deadline.

Data delivery should address three decisions: on the next hop, on the next packet to deliver and on the transmission moment. The choice of the next hop is generally based on geographic information. Node position awareness is definitely good as it presents low management cost, because computation is immediate, based on neighbor positions and neighbor knowledge alone is required. Thus, this technique does not suffer from route discovery delay and selected paths to destination are generally the shortest. Meanwhile, geographic forwarding is known to behave poorly to voids. It fails to discover routes in this context, and in the worst-case scenario, it may even fail to find paths, even if paths exist. Large voids make out of the Euclidean metric a poor approximation of the path length.

The choice of the packet to deliver is generally based on either the delay technique or on prioritization technique. Even though conceptually, two different techniques are identified, the former is implemented using priorities. The default queuing algorithm (FIFO) is insufficient, as it does not make decisions based on priorities. A FIFO queue would cause packet drops, even for high priority packets, due to capacity limitation. Instead, Priority Queuing (PQ) is suggested as one of the applicable sensor approach to meet the desired QoS for real time traffic.

The choice of the transmission moment depends completely on the MAC layer.

Two main challenges concern packet delivery in sensor networks with respect to real time communications: what about delivery in GPS-free systems, and integrating priority queues while still assuring portability? Node geo-localization may be an expensive mechanism for largely-deployed networks. The GPS technique may be partially used (beacon nodes alone are location-aware), but these strategies may generate important computation overhead and error. Moreover, GPS solutions are not available in any type of environment. Priority queues are generally implemented in the MAC layer. MAC level solutions require re-engineering of the sensor radio hardware and firmware, making deployment difficult and potentially causing interoperability problems with hardware supporting different MAC protocols.

Existing works partially integrate the following factors which may influence real time communications:

- *energy* - the most critical resource in sensor networks. Limited by the capacity of batteries, sensor lifetime need to be maximized, not only to assure environment sensing, but also to assure packet relay in multi-hop sensor networks. Decreased network connectivity may result in disconnected sub-networks or in void appearance. Evenly distributed energy drain may help to increase the network lifetime. The challenge here concerns methods allowing energy estimation. Network energy efficiency while assuring real time communications is a trade-off. We identify two main directions in integrating energy in these constraint and QoS systems: energy-awareness and energy-exploitation. Only the first is currently proposed in existing works, either adapting transmission power, or scheduling judiciously activity and sleep periods for sensors [10]. Energy-awareness makes systems aware of the energy challenge, trying to minimize energy consumption. Energy-exploitation solutions would directly use energy information as decisional joint criteria.
- *bandwidth* - a constraint which directly affects packet deadlines. Under load exceeding the available network bandwidth, the network should respond by either discarding packets or by queuing them, avoiding congestion periods, while still assuring at least partial packet delivery in the requested deadlines. This design consideration may be interesting especially in heterogeneous contexts.
- *power control* - small-range multi-hop communication is proved less costly in energy than long-range ones. Meanwhile, the increased number of hops expands the packet delay by accumulation. A trade-off is expected in order to assure minimum delay due to multi-hop transmissions and minimum energy consumption due to modified transmission power. This parameter is thus closely related to the energy parameter. Transmission power control is rarely exploited because it requires specific hardware which is not so widely integrated in sensor design.

C. Evaluation metrics

In supporting real time QoS for wireless sensor communications, several performance metrics are particularly interested to be evaluated:

- *end-to-end delay* is defined by the time taken for a packet to be transmitted across the network from source to destination,
- *deadline miss ratio* is defined by the number of packets which miss their deadlines over the number of initiated packets,
- *packet drop ratio* is defined by the number of packets which have been dropped before reaching destination over the number of initiated packets,
- *delivery ratio* is defined by the number of packets delivered over the number of initiated packets.

V. Concluding remarks

One parameter of quality of service is providing time guarantees for data delivery. This is particularly the case for wireless sensor networks when used in surveillance, detection of particular environmental events, generally critical. The inherent trade-off between guaranteeing that communications meet real time constraints and assuring energy-efficiency, robustness and scalability is characteristic for these networks. In this article, we identify the major tendencies of real time management in wireless sensor networks and propose future directions in this context.

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