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Real Time Data Acquisition in Wireless Sensor Networks

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1. Introduction

Implementation of low cost sensor nodes in recent years allow sensor nodes to be applicable in many different areas e.g. environment monitoring, homeland security and disaster relief operations. One major contribution is their high demand on data acquisition. Real-time data acquisition is more challenging and promising issue in these application areas. There are many approaches and solutions proposed for real-time data acquisition in the literature. In this chapter, we focus on real-time data acquisition in wireless sensor networks.

Wireless Sensor Networks (WSNs) consist of many tiny wireless sensors which operate in an environment in order to collect data for a specific mission. In most type of WSNs, once sensor nodes are deployed, thereafter no additional actions are employed. In a typical WSN, data is gathered from the environment by sensor nodes, aggregated in intermediate nodes and then transmitted to a base station. Because all these operations are executed by sensor nodes with limited power in a wireless media; reliable communication, power efficiency and network survivability issues are among critical concerns. WSNs are different from traditional networks because of their inherent characteristics. The specific properties of these networks pose various challenges such as energy consumption, limited bandwidth, and low storage. In the following sections we will introduce these constraints in detail.

WSNs can be used in a wide range of application areas. Networks e.g. composed of video and audio sensors can be used to provide monitoring and surveillance systems or can be used to enhance the existing ones. Some critical areas for homeland security, such as borders, gulfs, strait entrances and port approach waters, are subject to enemy infiltration in crisis and in wartime. Using an instantly deployable network composed of sensor nodes in these operation areas would be a good solution to increase the probability of detecting a penetration in a cost effective and efficient way than the conventional ones. Some applications, e.g. military operations, introduce additional requirements on sensor and ad-hoc networks such as reliability and operating in real-time. Limited battery life of the nodes requires efficient energy consumption techniques which challenge real-time and reliability requirements.

There are many routing approaches to provide either or both of the objectives of reducing the end-to-end delay and providing the reliability. However, most of these routing approaches challenge with other aspects such as energy-efficiency, long-lifetime and low-cost expect of the system. Energy aware protocols in the literature generally use multi-hop paths to use energy more efficiently. However, increase in number of hops between the source and the destination nodes bears some issues that must be considered (Monaco et al, 2006) (Du et al, 2006). First of all, nodes close to the sink deplete their energies quickly; leaving the sink unreachable and forcing the system into off-state (Yuan et al, 2007). Secondly, increase in the hop-number cause more nodes to buffer the packet on-the-route, causing a processing overhead and delay at in-between nodes. Processing overhead and buffer fill-up may cause packets to be dropped. On the other hand, delay at nodes may prevent to fulfill the real-time requirements of the system (Monaco et al, 2006). As the network size grows, the length of the constructed paths will increase, causing the problem described above more challenging. New routing techniques which provide reliability and real-time response to sensor readings in energy efficient way are always required in Wireless Sensor and Ad Hoc Networks.

Mobility is the other major concern that hardens the problem. Mobility of nodes degrades the performance of the system, making the problem more challenging and impractical. Mobility introduces additional overhead, increases complexity and makes the conventional routing algorithms fail. Therefore, novel and special algorithms are required for mobile environments.

In this study we introduce and discuss some proposed MAC protocols, routing protocols and aggregation techniques which address real-time needs in literature. Then we present two applications for real-time data acquisition using WSN. The structure of this chapter is as follows. In Section 2, we define real time data acquisition and relevant constraints. Real time communication issues are also discussed in this section. MAC layer and network layer protocols are presented in Section 3 and Section 4, respectively. In Section 5, aggregation techniques are stated. We give two sample Real-Time WSN applications in Section 6.

2. Real-time data acquisition

Real-time data acquisition can be stated as collecting, processing and transmitting data in predetermined latency boundaries. It mainly includes sampling, MAC layer operations, network layer routing, data aggregation and some additional processes.

Real-time data acquisition is a mandatory issue which must be considered in some WSN applications. This application may be a surveillance system, a temperature detector (He et al, 2006)(Lu et al, 2005), fire monitoring or intruder tracking system. Thus, the sensor data will be valid only within limited time duration (Felemban et al, 2005).

Real-time QoS is classified into two categories: hard real-time and soft real-time. In hard real-time, end-to-end delay boundaries are described as deterministic values. Latency in a message's delivery higher than this value will be a failure. However in soft real-time, a probabilistic latency value is used and some delay delay is tolerable (Li et al, 2007). The delay metric in every process stage determines the latency issues in algorithms and approaches. So in order to design a real-time WSN system, each process stage should be well designed.

2.1 Real time data acquisition constraints in WSN

In [Akyildiz et al, 2002], constraints in WSN are classified as sensor node constraints and networking constraints. These constraints also affect the real time data acquisition. In the Section 2.2, we present relations between real time data acquisition and these constraints.

2.1.1 Sensor node constraints

These constraints are mostly hardware related. The capabilities and constraints of a sensor node's hardware affect the latency. These constraints are listed as follows:

Limited Memory and Storage Space: The data size is important in guaranteeing real time data acquisition because sensor nodes are small devices and they have limited storage spaces, memories and processors. For example, there must be sufficient memory space and processor in order to aggregate data. If this process is executed by non-sufficient memory nodes, this may increase delay.

Energy Limitation: Energy is consumed during both computation and communication processes within a node. Energy limitation is one major constraint that affects the capabilities of sensor nodes extremely. Optimal solutions must be determined in order to transmit real-time data while consuming low communication power. Energy consumption in aggregation process is another critical issue.

Environmental Limitations: Sensor nodes have to struggle with many environmental difficulties such as physical obstacles, node terminations, unpredictable errors that avoid functioning of nodes, or communication interferences

2.1.2 Networking constraints

In addition to hardware-related constraints, real-time data acquisition in WSNs is affected by network-related constraints.

Communication Constraints: In order to provide a real time communication scheme between nodes, some preventive actions have to be taken. The relevant subjects of communication constraints are: [Akyildiz et al, 2002].

- Unreliable communication
- Bandwidth limitation
- Frequent routing changes
- Channel error rate

Additional Limitations: Most WSNs are deployed for specific reasons or objectives. This emerges new constraints specific to the applied area.

- Node mobility
- Intermittent connectivity
- Isolated subgroups
- Population density

In order to guarantee real time requirements all these constraints must be considered.

2.2 Real-time communications in WSNs

In this section we define the communication issues in MAC protocols, routing protocols and data aggregation process. We try to emphasize how these affect real time communication.

High utilization of bandwidth, reducing collisions, low latency, dynamic and fast operation of medium access control mechanism, fairness along with ensuring energy efficiency are among major concerns for a WSN's performance. A MAC algorithm must also achieve fairness, where every node should be allowed to transmit its data by considering efficiency and urgency.

A MAC protocol may adopt a distributed or a centralized approach. A distributed MAC protocol, where each sensor node determines its cycle behavior, is simple and easy-to-implement. This approach, however, is susceptible to collisions that reduce bandwidth utilizations and efficiency. The other type of MAC protocol, that is the centralized one, provides easy medium access management, simple synchronization, and low packet losses due to the frequency differences. However, such a protocol has some drawbacks; relatively short lifetime of cluster-head nodes, registration requirements, and additional energy consumption of mobile nodes when registering to a new cluster-head. MAC layer collisions increase end-to-end latency, jitter, and time-outs. Retransmitted packets cause overheads and underutilize the limited bandwidth. In Section 3 we define more issues, related with MAC layer protocols.

The performance of a MAC algorithm affects the network layer routing algorithm. While MAC layer decides which node will use the medium to transmit, network layer decides the next node to transmit. Routing decision directly affects end-to-end latency, congestion and bandwidth utilization. A routing protocol includes discovery of neighborhood, selection of next forwarding node, traffic load balancing and congestion handling processes. For a real-time system, all the issues mentioned must be provided with minimum jitter in a given time limitation. We detail network layer routing protocols in Section 5.

Another key concern in WSN communication is data aggregation, in which sensed data is combined into a single message and then, transmitted to a base station (Heinzelman et al., 2000) by sensors. The goal of data aggregation is to reduce the communication load which directly affects the efficiency of MAC protocol and network layer routing in a WSN. Such an operation must be organized in a systematic way because data aggregation increases latency and energy consumption. In adaptation of an aggregation technique, causative latency and energy consumption should be considered.

3. Medium access in WSNs

Wireless communications use a shared medium. This means that in a signal range, in one period of time, only one instance can send data. It is the MAC protocol's duty to transmit frames over this medium. Because of the limitations of power and network lifetime, the medium access process is harder due to the low-duty cycles of the nodes within a WSN.

Designing a good MAC protocol requires taking several parameters into consideration. Energy efficiency, scalability, adaptability, reliability, throughput, utilization of bandwidth, and latency are among these. We focus on, first, energy consumption issue, and then, low latency data delivery issue which is required for real-time applications. We present the energy wastage reasons in MAC protocols, and then discuss the proposed MAC protocols from the real-time communication view, and lastly present a comparison table of the protocols.

3.1 Reasons of energy waste

The most energy wastage sources in MAC protocols for WSNs are (Demirkol et al, 2006) defined as follows. The first one is *collisions*, when a node receives more two or more packets simultaneously. The retransmission of the collided packets increases the energy consumption. The second one is *idle-listening*. This occurs when a node listens an idle channel to receive traffic. The third one is *overhearing*, that means a sensor node receives packets that are destined for other nodes. The fourth one is control packet *overheads*. These packets are required to control the access to the channel. The fifth one is *over-emitting*. This occurs when a message is transmitted to a destination node which is not ready to receive. Additionally, transition between cycles of sleep, idle, receive and transmit also increases energy consumption. All these factors must be paid attention for designing an energy efficient protocol.

Another issue for reducing the energy consumption is that MAC protocols have a policy for duty cycles and switching off the radio. Basic protocols use a *fixed duty cycle*, and some others implement *adaptive duty cycle*, in which they adapt to changes in traffic over time and place (Langendoen, 2007).

3.2 IEEE 802.11

It is the standard for WLANs. It provides low latency and high throughput, but due to idle listening, its energy consumption is high. Therefore this protocol cannot be used for WSNs (Ye at al, 2001).

3.3 Real time MAC approaches

In WSNs, bandwidth utilization, channel access delay and energy consumption parameters are mainly determined by the MAC protocol. Considering a layered protocol stack, routing in the network layer determines the end-to-end or multi-hop delay, as the MAC layer settles single-hop or channel access delay. There are also cross-layer approaches developed in the literature for an optimized communication (Li et al, 2007) as discussed in Section 3.4.

I-EDF: (Caccamo et al., 2002) Implicit Prioritized Access Protocol (I-EDF) guarantees a HRT delay, using cellular backbone network. It offers collision-free communication via its mixed TDMA and FDMA scheme. It assures high throughput even in high loads.

Dual-Mode MAC Protocol: (Watteyne et al., 2006) supports HRT which adapts a linear network with identical nodes. In order to achieve a collision-free communication, it uses TDMA for global synchronization and a mixed FDMA-TMA scheme is adopted. Energy-efficiency is also aimed in this protocol.

DMAC: (Lu et al., 2004) was proposed for unidirectional data gathering trees. It balances the nodes' active/sleep cycles due to their depths on tree, thus eliminates the sleep delay, and incessant traffic forwarding is achieved. It is shown that DMAC is both energy efficient and low-delay bounded.

SIFT: (Jamieson et al., 2003) SIFT is designed for event-driven applications. To select a slot within the slotted contention window, a probability distribution function is used. It is efficient in terms of latency when many nodes want to send packets, however related energy consumption is a trade-off. Also, it introduces idle-listening and overhearing.

DSMAC: (Lin et al, 2004) Dynamic Sensor MAC has dynamic duty cycle property in addition to S-MAC (Ye et al.,2004). Decreasing the latency is the primary goal. Nodes have a SYNC period where sleep cycles are shortened when needed. It has better latency than S-MAC.

DB-MAC: (Bacco et al., 2004) It is a contention-based protocol aimed for reducing the delay in hierarchically structured applications. It employs a prioritized access mechanism and therefore reduces energy consumption and delay.

Z-MAC: (Rhee et al., 2005) It applies dynamic shift between SDMA and TDMA. It is topology-aware and performs well when there is high contention.

PEDAMACS: (Ergen & Varaiya, 2006) It has high powered access points which can be reached by one hop. They gather topology information and apply a scheduling algorithm. Bounded delay as well as energy efficiency is guaranteed.

A comparison of the afore mentioned MAC protocols is given in Table 1 to identify their QoS support and major differences.

Protocol Name	MAC Type	Latency/ RT Type	Energy Efficiency	Centralized/ Distributed	Scalability
*S-MAC	CSMA/CA	best effort	high	Distributed	good
*T-MAC	CSMA/CA	best effort	high	Distributed	good
*B-MAC	CSMA/CA	best effort	high	Distributed	good
I-EDF	FDMA-TDMA	HRT	NA	Centralized	moderate
Dual Mode MAC	FDMA-TDMA	HRT	NA	Centralized	moderate
D-MAC	contention-based	Best effort	Moderate	Distributed	good
DBMAC	contention-based	Best effort	High	Distributed	good
Z-MAC	CSMA-TDMA	Best effort	High	Hybrid	moderate
PEDEMACS	TDMA	HRT	High	Centralized	low
IEEE 802.15.4	Slotted CSMA/CA, GTS	Best effort / HRT	Moderate	Distributed	good
SIFT	CSMA/CA	Very low latency	Low	Distributed	
DSMAC	CSMA	Low latency	High	Distributed	good

Table 1. A comparison of MAC Protocols. "*" notated ones are non-real-time protocols.

3.4 Cross-layer solutions

There are some designs in the literature that aim to achieve real time parameters in a cross layer approach. This enables a higher layer to communicate with lower distant layers.
RAP: (Lu et al., 2002) Discussed in section 4.2.
MERLIN: (Ruzzelli et al., 2006) This protocol aims both low latency and energy efficiency, that combines MAC and routing protocols and applies a hybrid CSMA TDMA scheme. A schedule table is used to relay packets, in which the network is seperated into time regions with respect to hop numbers to the sink node.
VigilNet: (He et al., 2006) It is developed for real time target detection and tracking in a large area. It adapts multi path diffusion tree. Energy consumption is aimed as well. This application is detailed in section 6.1.
In summary, the parameters of a layer in the communication stack are reported to the next layer up. Coordination among lower and upper layers is made possible. There are two methods for a cross-layer design. The first one is to enhance the effectiveness of the protocol based on the parameters in other layers. The second one is to unite the related protocols in a single part. While this may allow a closer communication with all protocols, the connection is hard to distinguish. Also, the merged component's functionality can be very complicated. So it is preferable to allow transparency between the layers (Li et al, 2007).

4. Real time routing protocols in WSNs

Though the MAC layer can deliver packets considering real time needs, its effect remains local. Real-time requirements for end-to-end connections (or communication) should be satisfied. Routing protocols are those that should have ability to satisfy end-to-end real-time requirements (He et al., 2003). They are provided as either deterministic or probabilistic delay guarantee (Li et al., 2007).

4.1 Real time routing protocols design issues

End-to-end delay is mainly affected by the applied routing scheme. Therefore, some design issues must be considered in the design of routing protocols. These issues are well summarized in (Akyıldız et al., 2002) and (Al-Karaki & Kamal, 2004) as follows:

Energy consumption: Sensor node lifetime shows a strong dependence on the battery lifetime (Heinzelman et al., 2000). Each sensor in a WSN can act as a relay unit, hence energy consumption become as an important issue. If energy consumption is not managed properly, some node's batteries may exhaust. These malfunctioning nodes can cause topological changes and might require rerouting of packets and reorganization of the network (Al-Karaki & Kamal, 2004). It is to note that reorganization and rerouting processes increase the end-to-end-delay.

Data Reporting Model: This issue affects the delivering latency of a data packet. The data delivering method can be categorized as either time-driven, event-driven, query-driven, and hybrid (Al-Karaki & Kamal, 2004). Event-driven and time-driven (with low period) approaches can be considered in real time routing protocols.

Fault Tolerance: Some sensor nodes may fail because of internal or external reasons such as power exhaustion or environmental factors. In addition to MAC layer, the routing protocols have to find new forwarding choices in order to relay the data timely or in a low latency bound (Al-Karaki & Kamal, 2004). So while designing a real time routing protocol fault tolerance techniques must be determined.

Scalability: With the increase of the network size, the management would become more complicated. A real time routing protocol should be scalable enough to respond to events in the environment timely (Al-Karaki & Kamal, 2004). In order to relay a delay-constraint data time-synchronization techniques may be while coordinating a huge network.

Network Dynamics: It is to note that a network is a dynamic form which can adjust themselves according to environmental factors and needs. For example the location of nodes or the amount of data can change in time. These changes may cause some delay while transmitting a data. The real time routing protocol must consider such as network dynamics.

Transmission Media: This part is discussed in Section 3.

Quality of Service: In addition to bounded latency some routing protocols have to concern other QoS metrics such as accuracy or long network lifetime. Hence real time routing protocols are required to capture these requirements.

These issues are not the only ones which can be used to distinguish the routing protocols. But they are the mandatory ones. While designing a routing protocol which addresses real time or latency, these issues must be concerned in all steps.

4.2 Real time routing protocols

A number of real time routing protocols are proposed for WSNs in literature. We can list key real time routing protocols as follows:

RAP is the first routing protocol (Lu et al., 2002) which addresses real time requirements using a cross-layer design. In RAP each packet is given a prioritization level called as requested velocity and this parameter of each packet is determined locally. It is assumed in protocol, the routing layer is aware of physical geography.

SPEED (He et al., 2003) can be considered as a benchmark real time routing protocol among others. It affords three types of real-time communication services as real-time unicast, real-time area-multicast and real-time area-anycast. SPEED bases on a stateless non-deterministic geographic forwarding routing protocol which enables to find a next hop that is closer to the destination with its location aware structure.

Another real time routing protocol is MMSPEED (Felemban et al., 2005) which can be stated as an extension of SPEED. It is designed to provide a timeliness and reliable routing schema as an approach between the network and the MAC layers. The main difference of MMSPEED from SPEED is supporting different delivery velocities and levels of reliability.

A real-time power-aware routing (RPAR) protocol (Chipara et al., 2006) is proposed to adapt the transmission power and routing decision mechanisms dynamically. RPAR differs from the above protocols via the following features:

- Trade-off between energy consumption and communication delay
- A novel approach to handle lossy links
- Neighborhood management mechanism

Pothuri et al proposes an energy efficient delay-constrained heuristic solution (Pothuri, 2006) which is based on estimating of end-to-end delay. It is to note that the proposed algorithm is well suitable for small scale WSN applications.

Cheng et al introduce a novel real time routing protocol (Cheng et al., 2006) in which all path's end-to-end delay requirements are determined. In the proposed study each sensor node can decide its forwarding node due to the value of the links requirements. So it is not necessary to calculate the sum of each link's delay along the path. Hence the proposed algorithm differ from with its reduced overhead and simplified route discovery mechanism.

Directional Geographical Real-Time Routing (DGR) protocol's goal is to find a solution for real time video streaming while taking into consideration a number of resource and performance constraints (Chen et al., 2007). It proposes a novel multipath routing schema which regards forward error correction (FEC) coding.

Real Time Load Distributed Routing Protocol (RTLD) (Ali et al., 2008) aims link reliability and packet velocity through one-hop while providing energy efficiency in real time communication. In RTLD, the forwarding node is determined via optimal values of velocity, called PRR and the remaining power. It differs from other real time routing protocols with its feature which utilize the remaining power parameter to select the forwarding candidate node.

Soyturk and Altilar introduce a novel real time data acquisition approach (Soyturk&Altilar, 2008) which can also be used for rapidly deployable Mission-Critical Wireless Sensor Networks. It is based on the real-time routing algorithm, namely Stateless Weighted

Routing (SWR) algorithm. Data is carried over multiple paths simultaneously to provide reliability and to provide time limitations. It is a completely stateless routing approach that nodes do not need any topology knowledge for routing. Algorithm is simple and efficient which reduces the complexity at nodes and hence provides low-cost architecture.
In the proposed approach the routing tables are not hold in nodes thus they don't know their neighbors' information. The routing decision is made due to weight values of nodes. These values are calculated from geographical position and some QoS parameters, as shown in Equation (1);

$$\text{weight of node } i\,,\quad w_i = location_i + parameters_i + parameters_{network} \qquad (1)$$

These weight values of nodes are depend on remaining power or else. This technique reduces delay, energy consumption and processing requirement. The existing packet header and QoS fields in SWR are depicted in Fig. 1.

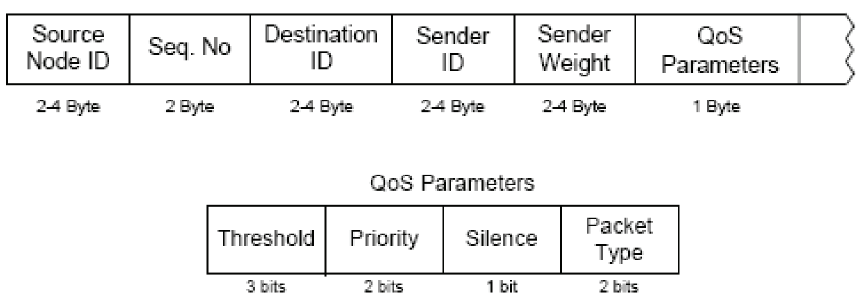

Fig. 1. Simple packet header and its QoS fields (Soyturk&Altilar, 2008)

Basically the SWR works as follows (Soyturk&Altilar, 2006): The source node determines the weight value of packet and adjusts this value into the packet then broadcast it. When an intermediate node receives packet, it compares the packet's weight value and its own weight value. If its weight value is smaller than the transmitting node's weight value and the destination's weight value (that is *0* for sink), it rebroadcasts the packet, otherwise drops the packet.
The proposed algorithm (Soyturk & Altilar, 2006):

- provides scalability since neither routing tables nor beaconing is used.
- simplifies the routing process by designing an appropriate algorithm which utilizes a weight metric.
- decreases calculations, delay, and resource requirements (such as processor and memory) at nodes since a weight metric is used instead of time consuming operations on routing tables.
- decreases energy consumption by;
  - not beaconing,
  - considering the remaining energy levels at nodes,
  - limiting the number of relaying nodes.
- provides reliability by exploiting multiple paths and recovering from voids.
- executes routing process completely in the network layer, independent of the MAC layer underneath.

The key contribution of SWR is eliminating the communication overhead and energy consumption produced in topology learning approaches. SWR utilizes resources allowing data flow over multiple paths rather than prior topology learning and path construction. Simulations prove that SWR is scalable in both large and mobile networks.

4.3 Comparison of routing protocols in WSN

We compare routing protocols stated above according to basic criteria (1-7) and functional criteria (8-11) in Table 2. This comparison is based on the issues defined in the chapter. No additional experiments or simulation is made to evaluate them. We do not include (Chen et al., 2007) and (Pothuri,2006) to comparison list because the stated criteria of them are not enough to fill the table and not fully correspond our criteria.

5. Real time data aggregation in WSN

5.1 Delay considerations for real-time data aggregation

In WSN, nodes sense and transmit data to the base station or a sink node. Base station or the sink node has to perform data collecting in a systematic way while considering constraints in WSN. Among collected data, there needs to be some correlation and combining processes in order to achieve high quality information delivery. This can be accomplished by data aggregation. Data aggregation is defined as *"the process of gathering the data from multiple sensors in order to eliminate redundant transmission and provide united and meaningful information to the base station"* (Rajagopalan & Varshney, 2006). The main goal of data aggregation is to enhance network lifetime by reducing transmission power consumption in addition to increase the quality of delivered information.

If we figure out data aggregation in a tree based approach, which is shown in Fig. 2, E aggregates packets of B and A.

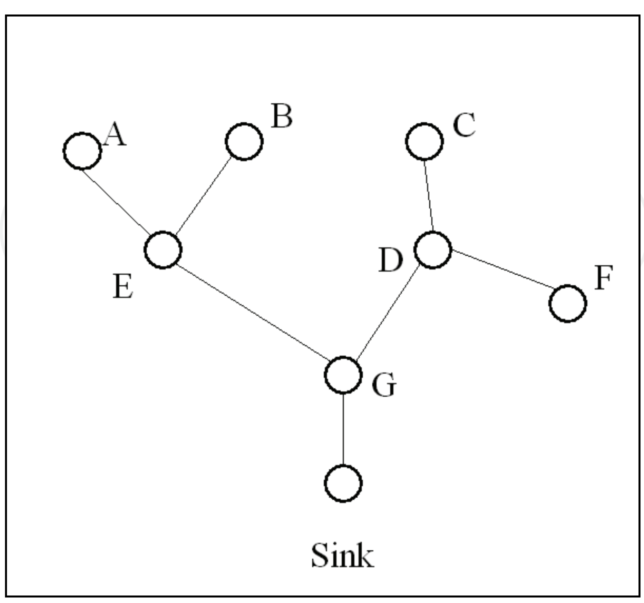

Fig. 2. An example of data aggregation (Heinzelman et al., 2000)

No	Criteria	RAP	SPEED	MM-SPEED	RPAR	RTLD	(Soyturk 20
1.	**Control packet overhead**	Moderate	Moderate	Low	Low	Low	Lo
2.	**Energy Consumption**	N.M.	Moderate	N.M.	Moderate	Low	Lo
3.	**Reliability**	N.M.	N.M.	Moderate	N.M.	High	H
4.	Algorithm Complexity	N.M.	Moderate	High	N.M.	N.M.	Lo
5.	**Void avoidance/ recovery**	N.M.	Yes	Yes	Yes	N.M.	Y
6.	**Scalability**	Large Scale and High Density	Medium scale and high density networks	Large scale and high density networks	Large Scale Networks	N.M.	Large Sc Densi Missior
7.	**Node Discovery Methodology**	Nodes are aware of physical geography	Beacon exchange mechanism	Via periodic location update packets	On-demand neigborhood management	Via invoke packet	Nodes do to kno neig

N.M. : This feature is *not mentioned* in protocol

Table 2. Comparison of Delay-Constraint Routing Protocols in WSNs

No	Criteria	RAP	SPEED	MM-SPEED	RPAR	RTLD	(Soyturk& 2006
8.	**Forwarding node selection criteria**	Select node, has the shortest geographic distance	Select node, meets with packet delay requirements	Select node set, meets with packet's speed level	Select the most energy-efficient node, meets the packet's required velocity.	Select node set, meets with the delay requirements and remaining power	Packe broadcas nodes. No have the weight va packet's rebroad
9.	**Real-time achiving methodology**	Prioritize due to velocity of packets	Select node, has the min delay parameter	Multiple packet delivery approach	Via Dynamic velocity assignment policy	Select appropriate node due to end-to-end delay with the best PRR value and remaining power	Via pa classificatio QoS me
10.	**Energy Consumption Reducing Strategy**	N.M.	Via stateless non-deterministic geographic forwarding	N.M.	Adapts variable transmission power.	Adapting transceiver states	Via thresh and node consume e discove neighb
11.	**Location Awareness Strategy**	Via GPS or other location services	Via beacon packets	Via GPS or other location services	Via GPS or other location services	Via pre-determined neighbor nodes	Via GPS o location s

N.M. : This feature is *not mentioned* in protocol

Table 2. Comparison of Delay-Constraint Routing Protocols in WSNs (continued).

In (Krishnamachari et al., 2002) two methods of data aggregation are defined: optimal aggregation and suboptimal aggregation. In optimal aggregation, all the sources send a single packet to the same receiver through an aggregation tree. In the suboptimal aggregation, sources send packets to different destinations which are determined by distance or greedy approaches.
The design of data aggregation schema affects delay parameters. For example, if sensor nodes whose packets will be aggregated are in different distances to the sink node, the receiving times of packets to the sink node may vary. In Fig. 3, A is the aggregator node. If E and B transmit simultaneously, the arriving times of E's packet and B's packet will be different. It is to note that the aggregation process in an aggregator node increases delay (Krishnamachari et al., 2002).
According to these considerations, trade-off between delay and energy consumption become an important issue while designing an aggregation schema. Also, the delay tolerance of the application is an important factor, affects the optimality of the data aggregation method (Zhu et al., 2005). So delay boundaries must be determined for achieving maximum energy efficient structure (Zhu et al., 2005).
There exists such data aggregation methods, focus on energy efficiency, network lifetime and data accuracy in literature. In the following subsection we present the basic functionality of the delay constraint data aggregation algorithms due to their introduced features.

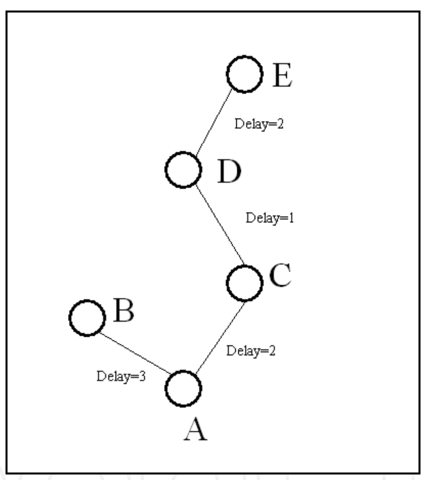

Fig. 3. Distance and delay interaction (Krishnamachari et al., 2002)

5.2 Delay constraint data aggregation algorithms

In literature, a number of data aggregation methods are proposed which address latency, reliability and energy consumption issues. In this section we mention data aggregation methods whose features meet real time requirements while considering other issues.
We start with Upadhyayula et al's (2003) study which proposes a CDMA/TDMA based algorithm that constructs a tree and schedules its nodes for collision-free transmission. The aim of the proposed study is to establish a network which requires fast and reliable data aggregation by considering energy efficiency.
In the proposed study the increase of parallel data transmissions reduce the latency. Hence required delay boundaries are achieved via constructed balanced tree.

Yu et al. (2006) proposed a delay-constraint data aggregation schema which addresses packet scheduling in a general tree structure while considering a real time latency constraint.
Yu et al. (2006) indicate that "the transmission energy does not monotonically decrease as the transmission time increases – the transmission energy may increase when the transmission time exceeds some threshold value" Also a model is introduced which describes the tradeoff between energy and latency. The energy-latency trade-off function w(τ) is described as follows (Yu et al., 2006):

$$w(\tau) = [C \cdot (2^{\frac{s}{\tau \cdot R}} - 1) + F] \cdot \tau \cdot R \quad (2)$$

Also the energy-latency function curve for long range and short range communication is figured as follows:

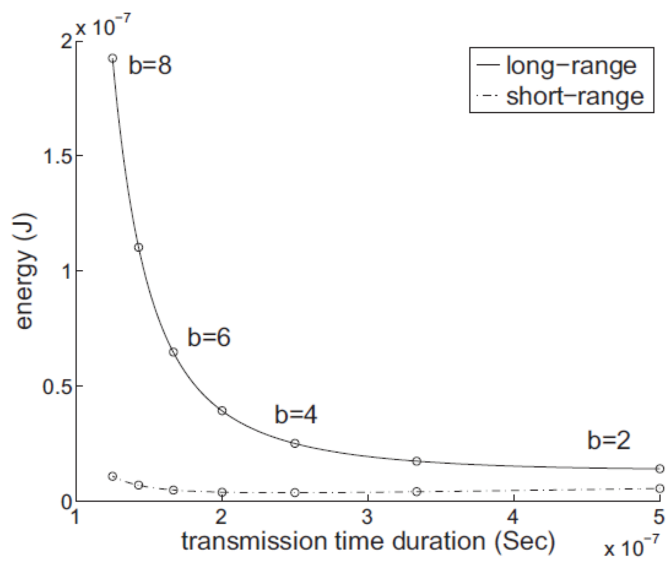

Fig. 4. Energy-latency function curve (Yu et al., 2006)

Cheng et al. (2006) propose a heuristic algorithm for real-time data aggregation. The authors consider two constraints such as node degree bounded, where the maximum node degree shall not exceed a bound; and tree height bounded, where the tree height shall not exceed a bound. In the proposed study it is stated that the maximum node degree of the Minimum Spanning Tree in the plane is six which can be reduced to five. Also Cheng et al., (2006) propose three heuristic algorithms to minimize total energy cost under the latency constraint. These algorithms are node first heuristic, tree first heuristic and hop bounded heuristic. More details about these algorithms are stated in Cheng et al. (2006).
Akkaya et al. (2005) propose an efficient aggregation method for delay-constrained data. The proposed study investigates the problem of efficient in-network data aggregation of delay-constrained traffic in wireless sensor networks. Authors consider both real time and non-real time data while designing the proposed method. Real-time data are generated and relayed to the gateway in response to delay-sensitive queries.
There is a real time queue at each relay node for the incoming packets of these multiple flows which is described in Fig.5 (Akkaya et al., 2005). The purpose of having a different queue is to enhance storage capacity of a sensor node and to generate real time flows depending on the number of active real time source sensors.

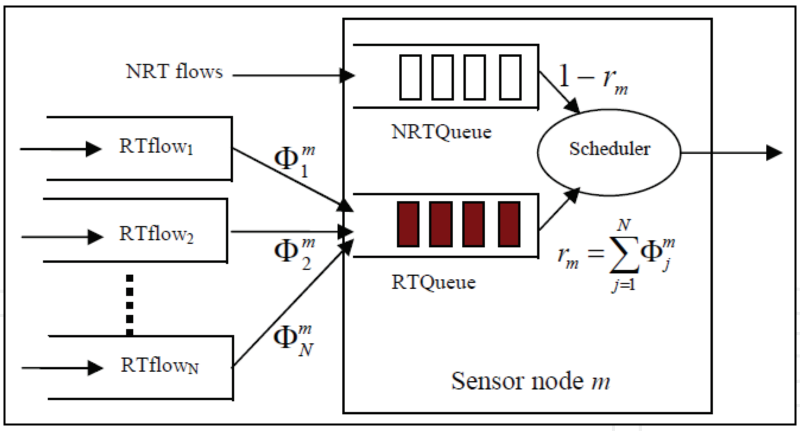

Fig. 5. Queuing model on sensors (Akkaya & Younis, 2004)

We have compared the delay-constraint data aggregation methods, stated above according to tree construction and energy-latency trade-off approaches.
A comparasion of these techniques are depicted in Table 3.

	Data Gathering Tree Construction	**How manage energy-latency trade-off**
(Upadhyayula et al., 2003)	Propose a CDMA/TDMA based algorithm which adds new nodes to the least weight branch.	Constructing a balanced tree. Establishing parent-child relationship with other nodes.
(Yu et al., 2006)	-	Rate adaptation techniques and non-monotonic energy model.
(Cheng et al., 2006)	Construct a degree bounded and height bounded tree via proposed algorithms	Use in order to obtain a Establish a spanning tree by heuristic algorithms. In the tree all nodes are no more than H hops away from the root.
(Akkaya et al., 2005)	It uses the Shortest Path Tree heuristic in order to build an initial aggregation tree.	A Weighted Fair Queuing based mechanism for packet scheduling is employed at each node.

Table 3. Real time latency data aggregation methodology

6. Real-time WSN applications

Applying the developed RT WSN methods over real-world applications shows their quality, applicability, and good or bad sides. Also, discussing such applications enables people to understand the structure of the methods more clearly. We examine design issues of Real Time WSN first, and then present some of the latest RT-WSN applications in industrial and academic field. In previous studies, researchers have classified WSN applications according to usage areas such as medical, military or community-related but it will be more useful to classify them according to their functionalities. We group applications as following:

- Surveillance applications
- Status monitoring
- Localization

- Motion monitoring

Design issues differ for each of these areas; however, real time parameters are the key issues for each group of applications. Real time requirements must be maintained while providing other requirements such as energy consumption and accuracy. Providing real time guarantee is conducted by using some predetermined deadline times, being probabilistic or deterministic. Deadline times must be short enough that the reaction taken by the system will be efficient. In most applications we examined, deadline times are divided into subdeadlines for each subprocess. We make a general list of subprocesses having subdeadlines:

- Initial Activation
- Sensing
- Wake-up
- Media Access
- Transmission
- Routing
- Aggregation
- Base Process

Most of these subprocesses exist in large scale networks, but small scale networks may not have all of them.

In these applications sensors may be mobile or fixed, and make a wireless communication with each other via single-hop or multi-hop. Sensors close to each other form a group, where each group communicates with other groups or base station by its cluster head. The base station is a device which coordinates the groups, compiles the data sent from them, and it has more enhanced resources compared to the nodes. The communication between the base station and cluster heads is generally single-hop, however in some applications it may be multi-hop. The base station relays the meaningful data it gathered to a main server or an end user via some media such as wired, satellite, 802.11 WLAN links.

There are numerous real time applications using WSNs. In this section, in order to support the real time issues stated previously, we limit our application examples in two. One sample application is a large scale network and the other is relatively small scale one that are both examples of latest Real-Time WSNs.

6.1 Sample application: Vigilnet - real time target tracking with WSN

The developed application in (He et al., 2006) detects fast moving targets in real time while considering energy consumption and accuracy. The system design is implemented due to the pre-determined latency boundaries. It is stated that for environment surveillance the rate of event occurrence is low, so the sensor nodes wait in idle state most of their lifetime. The sentry nodes wake up other nodes in the presence of critical events. If a target enters the area nodes in idle state are waken up and start to monitor and sample. All the sensors transit their data to a group leader which is responsible for aggregation, periodically. After the aggregation process group leaders report the event to the nearest base. It is to note that the communications between group members and group leader is one-hop, so the capabilities of group members are equal. After receiving event information to the base station, data is correlated by logical methods. The authors state some challenges while designing such a network. These design challenges are:

- *Selection of sentry nodes* and *determining its duty cycle* according to probability of event occurrence. This issue affects the coverage ratio of the whole area.
- *Minimizing the actuation delay*. The sufficient timeliness must be achieved in order to detect fast targets.
- *Designing fast detection algorithms*. It is to note that detection is a discrete event. The total data in these events must be met with a threshold value in order to decide an occurrence as an event. If detection delay is reduced, the detection confidence will increase simultaneously.
- *Designing effective wake-up services*. Nodes in 1% are awake and 99% are in idle state. If any transmission is received from sentry nodes in this tiny wake-up period, non-sentry nodes activate and start to monitor. If the tiny wake-up periods become longer, the activation time of node becomes minimal but energy consumption is increased.
- *Determining the degree of aggregation (DOA)*. As mentioned before, more aggregation process increases the level of accuracy but introduces additional energy consumption.
- *Classification of information*: In order to achieve a meaningful data, it is necessary to collect these data from many sources. For example, to determine a car's speed, the number of sources reporting must be at least 3. However collecting information from many sources causes some delay.

As a summary, (He et al., 2006) presents a complex real time sensing network design, where timeliness is guaranteed by sub-deadlines. This can be considered as a good example that figures out the trade-offs in design processes.

6.2 Sample application: real-time monitoring of hurricane winds with WSN

This application proposed in (Otero et al., 2009) is deployed in relatively medium scale. It remotely monitors the effects of hurricane winds on man-made structures like house or a factory (Otero et al., 2009) using wireless sensor network. The system architecture is illustrated in Fig. 6.

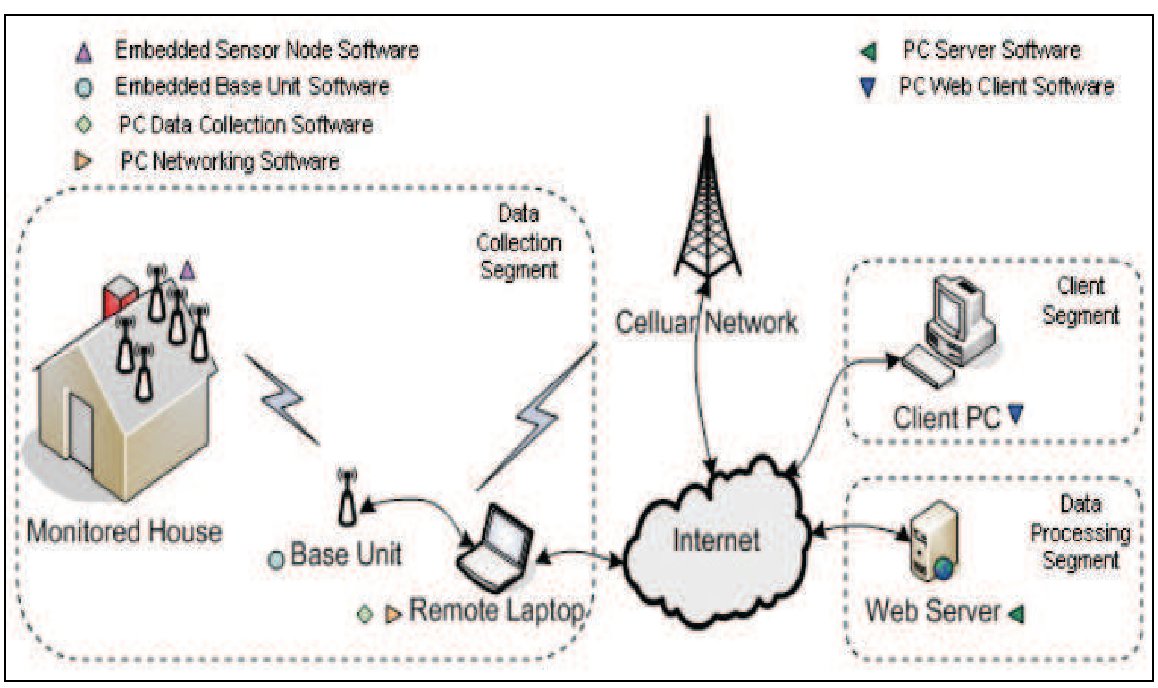

Fig. 6. System Architecture (Otero et al., 2009)

In (Otero et al., 2009), the real time requirements are not mentioned in numerical limits like in (He et al., 2006), but stated as 'near-real time'. In order to increase the communication performance between monitored house and remote laptop, the sampling node and transmission efficiency are considered as (Otero et al., 2009):

- Sampling rate must be at least 10 samples/second for pressure measurements.
- Nodes must transmit at least 5 MB of collected data to the remote site in every 5 minutes interval.

As mentioned above a time driven reporting schema is used. Basically system works as follows:

Data, collected by sensor nodes, are transmitted to a base station. This transmission is hold in one-hop and all the sensors have similar capabilities. Also the transmission of remote sensor nodes is managed by base station. A scheduling algorithm is used to assign internal transmission slots to remote sensor nodes (Otero et al., 2009). Nodes can only transmit their data in their active slots.

The key design issues stated in (Otero et al., 2009) are:

- Determining appropriate timing mechanisms between sensor nodes.
- Determining number of sensor nodes. It is to note that the density of nodes affects the timing problem.
- Developing or selecting appropriate compression algorithms. In this application, data is zipped rather than aggregated.

As a conclusion, this application uses a single-hop transmission, where due to the small deployment area and less number of nodes, zipping is used instead of aggregation in order to establish a simple architecture.

7. Conclusion

Data required for applications can be provided in several ways and with different methods. These methods constitute the data acquisition phase of these applications. Real-time data acquisition differs from usual data acquisition due to goals behind it and applied provision methods. While the usual (non-real time) data is used to make strategic level decisions, real-time data supports to make tactical decisions. Consumer of the real-time data, hence, should be supplied in a timely manner to fulfill consumer requirements. Time interval for real-time may change with respect to application needs either in terms of microseconds, milliseconds, seconds, or minutes. It should be fast enough to preserve the essential information associated with the event. Real time data is then processed immediately in order to make a decision or to make a reaction.

In this chapter, we overview real-time data acquisition in Wireless Sensor Networks. We present the approaches proposed in the literature and their primary positive and negative aspects. As described in the chapter, real-time data acquisition involves operations on multiple layers in the communication architecture. It becomes a complex task to manage in such a wireless communication network. Constraints and features peculiar to sensor networks harden the problem. We underline the key points and aspects in such a multi-tasking environment and present related studies in the literature.

While the medium access is mandatory issue that must be solved locally in real-time, end-to-end communication requirements drive the limits and shape the approaches to become efficient and applicable in WSN. We present the performance issues and factoring parameters for real-time data acquisition in WSN. Of the approaches that aim to solve one communication task, e.g. medium access or routing, we also present comparisons of them. These comparisons provide a snapshot view of the protocols and derive conclusions on how new approaches should be. Of the routing protocols, Stateless Weighted Routing (SWR) is one key protocol that aims to solve multiple objectives and problem in WSN. With respect to other protocols, SWR is the easiest and the simplest one to implement. It has many advantages and is superlative compared to other similar protocols.

While aggregation approaches are needed to reduce communication overhead, to provide efficient bandwidth usage, and to provide higher quality data, these approaches introduce delay. Moreover, aggregation is a complex task to be handled in identical tiny sensor nodes. Aggregation at more powerful nodes (with additional ability and higher resources) is more attractive solution.

There are applications that use real-time data aggregation via Wireless Sensor Networks. Of these, we present two and give design strategies of them. By increased demand on sensor applications, applications that use real-time data aggregation via WSN will increase in near future.

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Data Acquisition

Edited by Michele Vadursi

ISBN 978-953-307-193-0
Hard cover, 344 pages
Publisher Sciyo
Published online 28, September, 2010
Published in print edition September, 2010

The book is intended to be a collection of contributions providing a birdâ€™s eye view of some relevant multidisciplinary applications of data acquisition. While assuming that the reader is familiar with the basics of sampling theory and analog-to-digital conversion, the attention is focused on applied research and industrial applications of data acquisition. Even in the few cases when theoretical issues are investigated, the goal is making the theory comprehensible to a wide, application- oriented, audience.

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