Decision Support Algorithms and Optimization Techniques for Personal Homecare Environment

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Abstract— **In this paper, various decision support schemes are proposed evaluating the selection of different network infrastructures in terms of routing optimization and signal strength selection. Limited computational and radio communication capabilities require collaborative algorithms with energy-aware communication. Power saving makes it possible to guarantee basic levels of system performance, such as connectivity, throughput and delay, in the presence of both mobility-immobility and a large number of sensor nodes. A variety of approaches for intelligent energy-efficient schemes have been simulated over different performance metrics.**

I. Introduction

HOMECARE services bring hope, recovery and rehabilitation to home patients and their families every day. Tele-medicine applications cover the areas of emergency healthcare, homecare, patient tele-monitoring, tele-cardiology, tele-radiology, tele-pathology, tele-dermatology, tele-ophthalmology, tele-psychiatry and tele-surgery [1], [2]. These applications enable the provision of prompt and expert medical services in underserved locations, like rural health centers, ambulances, ships, trains, airplanes as well as at homes (homecare) [3], [4]. The combination of the medical profession's advanced procedures and equipment with the regional healthcare communication networks, may offer a complete, integrated healthcare delivery system made up of hospitals, outpatient services, pharmacies and a large rural home health operation. From the patient's perspective, that means not only having the necessary technology at hand, but also a centralized environment that is comfortable, convenient and dedicated to the care of their specific condition.

Wireless Sensor Networks (WSNs) have been increased dramatically the recent years as they are used more and more in the daily life. Medical, environmental and military sectors are some of the most important areas that the recent developments have been applied in. In order to guarantee the wireless sensor networks survivability and increase healthcare network lifetime in such special purpose environments, various energy-efficiency schemes have been proposed in the literature. In some cases, healthcare sensor networks are expected to be able to operate for a long period of time in standby, and transmit the gathered data when required, as soon as possible. Under theses assumptions, most of the time the network is not in operation, but the network nodes waste energy in the RECEIVE mode. Energy is a valuable commodity in wireless networks due to the limited battery of the portable devices. The energy problem becomes harder in ad-hoc wireless sensor networks due to their limitations arising from their nature. Except the application of the energy efficiency algorithms proposed [8-12], energy efficiency may be achieved by the proper choice of the available wireless technologies, ensuring the QoS provisioning for the specific healthcare application.

In order to confront this problem a decision algorithm is proposed, the main parts of which are as follows. First the algorithm checks for the available wireless technologies such as Wireless Local Area Networks (WLANs) or Wireless Personal Area Networks (WPANs). These technologies are GPRS/GSM/1XRTT/CDMA, ZigBee 802.15.5, WiFi 802.11b, and Bluetooth 802.15.1 respectively. Then the patient's biomedical information measurements (e.g. electrocardiogram (ECG), heart sound/rate, electroencephalogram (EEG), electromyography (EMG), body temperature etc.) are specified. The decision is taken targeting to maximization of the resource battery life of the patient's personal server (the amount of the absorbed radiation on the patient's body is also taken into account).

There are six basic parameters where their values are ranged for the patient's biomedical information measurements, namely: the voltage fluctuation, the number of the sensors used for acquiring the measurements, the bandwidth needed and the information rate for transferring the data as well as the sample rate and their resolutions values per sample. On the other hand, the technologies that support these measurements have different standards and features in respect to where the application is focused, what are the system's resources, the total amount of nodes per implemented network, the supported bandwidth as well as the coverage of each technology (varied from 1-100 meters in WPANs up to kilometers in WLANs).

The remainder of the paper is organized as follows. In Section II the aforementioned technologies for homecare services and applications, as well as, their requirements and

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limitations due to sensors are thoroughly described. Section III describes the energy-efficient schemes in terms of power-aware routing and maximum lifetime routing for wireless sensors networks. Section IV gives the overall performance of the proposed routing schemes as regards simulation results due to network selection and cost function techniques. Finally, Section V concludes the paper.

II. Homecare Network Challenges

A. Enabling Technologies

Wireless communications have recently become a disruptive technology for home networking and home automation designers. A key motivation for use of wireless technology is the reduction in installation cost, since new wiring is not needed. Wireless networking conveys information exchange with minimal installation effort. This trend follows from the wider availability of cheaper and highly integrated wireless components and the success of other wireless communication technologies such as cellular, Wi-Fi and WPANs.

The state-of-the-art of wireless communications networks for unconstructively and ubiquitously homecare communication incorporates a variety of applied wireless networks [5], such us Bluetooth using TDMA-Polling, HiperLAN/2 and HiSwan employing access-point techniques, and the 802.15 Family, for instance 802.15.1 Bluetooth Equivalent using TDMA-Polling, 802.15.3 High Rate WPAN, which can be a hybrid CSMA/S-ALOHA-TDMA scheme, 802.15.4 Low Rate WPAN using hybrid CSMA/S-CSMA. There are also some alternate schemes like Ultra Wide Band (UWB) usually being an IR-TH scheme, MC-CDMA with two-layered approach CDMA-TDMA to assure compatibility with 802.15.3, OFDM-TDMA that can be built on top of 802.15.3, 802.15.3a which can be MC-UWB or multi band OFDM UWB or MC-CDMA UWB.

The local infrastructure incorporates: 1) Local application items that provide some services to the user or to other application items, 2) Local servers that provide local communication capability for the local application items with user terminals, with other local application items, and with application items or user terminals in the global network through a global network access point and 3) A global service access point (hot spot), which the user can access services in the global network by the local communication technology with, and which is usually faster and cheaper than using the global wireless communication technology (e.g. GPRS, UMTS) in patient’s terminal. Interworking, between different network infrastructures, has already been studied and integrated in a wide-area tele-medicine platform for the provision of homecare services, based on the satellite DVB-RCS and Wi-Fi communication technologies [6].

B. Homecare Services and Applications

For homecare services there are several applications and solutions based on wireless sensors, improving monitoring accuracy of the patients. Vital signals can be monitored simultaneously, separately, stored and transmitted whenever there is network availability. Each provides different and complementary information on the well being of the subject and for each specific examinee the anticipated range of signal parameters is different.

The management of the patient with chronic illness, such as diabetes or respiratory disease, requires close observation of parameters of well being at times of vulnerability, with early intervention if the patient's condition deteriorates. In the case of diabetics, the monitoring of blood sugar levels resigns the patient to repeated blood sampling which is undesirable and invasive. One possible solution is the development of implantable wireless sensor devices that would be able to give this information quickly, and in a continuous fashion. Current conditions, where home monitoring might be provided, include: hypertension, diabetes (monitoring glucose), obesity (monitoring weight), CHF (monitoring weight), asthma and COPD (monitoring spirometry/peak flow), and, in the near future, conditions utilizing oximetry monitoring. Other home monitoring conditions might include pre-eclampsia, anorexia, low birth-weight infants, growth abnormalities, and arrhythmias. Most chronic health conditions in children and adults could be managed and/or enhanced by home monitoring.

C. Requirements and Limitations

For the area of e-health applications, various low-cost wireless sensor networks have been developed taking into account different technical issues. Energy, size, cost, mobility, infrastructure, network topology, connectivity and coverage are some of the requirements that the developer must take into consideration. The most important of all is size and power consumption. Varying size and cost constraints directly result in corresponding varying limits on the energy available, as well as on computing, storage and communication resources. Low-power requirements are necessary both for safety considerations and because, in mobile communications, the battery lifetime must be commensurate with the application, often several hours long. Hence, the energy and other resources available on a sensor node may also vary greatly from system to system. Power may be either stored or scavenged from the environment (e.g., by solar cells).

Mobility is another major issue for pervasive e-health applications because of the nature of users and applications and the easiness of the connectivity to other available wireless networks. Both off-body and personal area networks must not have line-of-sight (LoS) requirements. Consumers generally prefer wireless devices because wires can tangle, restrict movement, be tripped over, and get caught on other objects.

Problems arise especially between WLAN and WPAN networks since they both use the same unlicensed ISM frequency band. Some mechanisms have been developed to allow coexistence in the same frequency band. Frequency multiplexing, time division multiplexing and spatial diversity are some known access methods. Bluetooth and IEEE802.11b WLAN (Wi-Fi) use different access methods, namely Frequency Hopping Spread Spectrum (FHSS) and Direct Sequence Spread Spectrum (DSSS) techniques respectively. In any case, the performance of Bluetooth and Wi-Fi networks suffer from the existence of each other. The standardization body of WPAN is developing coexistence mechanisms to tackle the problem.

From the interworking point of view, protocols generally used in global networks, such as TCP/IP, http and ftp, should be preferred in local networks, even though they can increase the cost and power consumption of the local infrastructure.

III. Deployment Sensor Issues in Healthcare

Sensor networks are wireless networks consisting of an adequate number of small in size, inexpensive, low-power healthcare sensor nodes, which are densely deployed either inside the phenomenon or very close to it. Sensor nodes consist of sensing, processing and communicating components because their function is to collect and disseminate critical data while their position need not be predetermined [7]. Therefore, healthcare wireless sensor network protocols and algorithms must possess self-organizing capabilities. Wireless sensor networks bear important applications in healthcare, conferencing, monitoring disaster areas providing relief, home, environmental monitoring, file exchange, military purposes and gathering sensing information in inhospitable locations.

It is very important that the network architecture and power control schemes, applied on, should guarantee the network connectivity securely, with minimum delay and collisions and at the same time minimizing the energy consumption. Numerous different approaches on different network layers may be found in the literature for energy conservation. A comparison study on energy consumption of different ad-hoc routing protocols may be found in [8].

Since retransmission of frames leads to unnecessary wastage of energy, techniques such as frame transmissions (based on channel state sensing and reducing the number of collisions), can lead to efficient battery usage. Turning-off the transceiver during idle period and during period when the transmission is forbidden or not likely to be successful (e.g. the NAV period in IEEE 802.11) may lead to better energy-efficient MAC design. Some basic power conservation mechanisms in ad-hoc wireless sensor networks are described below.

A. *Power-Aware Multi-Access with Signaling (PAMAS)*

Power-Aware Multi-Access with Signaling (PAMAS) is a multi-access protocol for ad-hoc radio networks based on the original MACA protocol with the addition of a separate signaling channel [9]. It saves nodes' battery power, by turning off the nodes which are not in active transmission or sending packets. In PAMAS protocol the receiving mobile nodes transmit a busy tone (in a separate control channel) when they start receiving frames so that other mobile nodes know when to turn off. When a mobile node does not have data to transmit, it should power itself off if a neighbor begins transmitting to some other node. A node should turn off even if it has data to transmit if at least one of its neighbor-pairs is communicating. A mobile node, which has been turned off when one or more of its neighbor-pairs started communicating, can determine the length of time that it should be turned off by using a probe protocol. In this protocol, the node performs a binary search to determine the time when the current transmission will end.

B. *Sensor-MAC (S-MAC)*

Sensor-MAC (S-MAC) is a distributed protocol, which gives the possibility to nodes to discover their neighbors and build sensor networks for communication without being obliged to have master nodes. There are no clusters or cluster heads here. The topology is flat. This solution, proposed by [10], focuses mainly on the major energy wastage sources while achieving good scalability and collision avoidance capability. The major energy wastage sources may be classified into overhearing, idle listening, collisions and control packet overhead [11].

S-MAC introduces two techniques to achieve the reduction of energy consumption: i) neighboring nodes are synchronized to go to sleep periodically so that they do not waste energy when a neighboring node is transmitting to another node or by listening to an empty channel. The overhearing problem is avoided this way, and ii) the control packet overhead of the network is kept low because synchronized neighboring nodes form virtual clusters to synchronize their wake-up and sleep periods. Actually, there is no real clustering and no inter-cluster communication problem. The main components of the S-MAC protocol are: a) Periodic Listen and Sleep, b) Collision and Overhearing Avoidance and c) Message Passing.

C. *Periodic Hibernation*

According to this protocol, the wireless transceiver (transmitter/receiver) is powered off during the periods where the sensor node can neither transmit nor receive. In IEEE 802.11, a sensor node hearing NAV may switch to sleep mode, powering off the transceiver during this period. Here, it must be taken into consideration that the NAV timer always decreases (counts-down) regardless of the channel status. Note that, the back-off timer decreases only when medium is idle. In IEEE 802.11, every mobile node must wake up during an Announcement Traffic Indication Message (ATIM) period during which transmitters inform their destination not to go to power-save mode. If no notification is received, the mobile node can go to power-save mode and wake up in the next ATIM period [12].

Again, a transmitting mobile node can defer its transmission (or at least reduce its transmission rate) when channel quality is bad and may try to compensate the loss when the channel becomes better.

D. Geographic Adaptive Fidelity (GAF)

GAF was initially designed as a power-aware location-based routing algorithm for mobile ad-hoc networks, but is also applicable in sensor networks. This algorithm conserves energy by powering off sensor nodes, not needed in the network, without affecting much the level of routing fidelity. Each sensor node uses its location, which is indicated by Global Positioning System (GPS), in order to connect itself with a point in the virtual grid. Sensor nodes connected to the same point on the grid are considered equivalent in terms of the cost of packet routing. Energy is saved by keeping some sensor nodes, located in a particular grid area, in sleeping state. Hence, GAF can effectively increase the sensor network lifetime as the number of nodes augments. The sensor nodes' change of states, from sleeping to active, is done in turn and in such a way that the load is balanced.

IV. Performance Assessment

In the healthcare environment the connectivity between the monitoring applications with the medical data source may be assured by the use of different wireless technologies available. However, the decision of the proper technology used for the connection of the healthcare sensors with the healthcare monitoring network may be based on factors like the sensor lifetime or remaining lifetime, the minimization of the radiation to the patient, frequency that the system may change the batteries in the sensors, the type of the application and emergency nature of the information.

The energy efficiency part is crucial for the successful and continuous monitoring. Depending on the healthcare application, i.e. if the measurement is continuous, or in tactical time periods, resource demanding etc., energy efficiency may be achieved by the proper selection and use of the well-known algorithms presented above.

Consider an elderly patient living in a village or in an old people's home far away from a hospital, who is monitored remotely by the doctors. In such a case the battery change is not feasible to take place quite often. The selection of the used available technology may be based on the remaining energy in consideration with the next battery change. Also, the minimization of the radiation is another issue. Most of the times, it is better to select i.e. a WLAN technology instead of a WPAN, since the fluctuation of the radiation in different technologies depends on the signal strength of the transmitter. Finally, the emergency type of the application, characterized by specific metrics (jitter, delay, bandwidth etc) and the network condition may influence the interface selection.

A. Network Selection

The decision algorithm is easy to be applied when strength is below a threshold or the QoS is very low. According to the signal strength point of view, the total received power is given by the expression (all units in dB)

$$P_r = P_t + G_t + G_r - PL \qquad (1)$$

where P_r is the received power, P_t is the transmitted power, G_t and G_r are the antenna gain of the transmitter and receiver respectively and PL is the signal path loss given by

$$PL(dB) = 20\log\left(f_{MHz}\right) + 20\log\left(d_{km}\right) + 32.45 \qquad (2)$$

In such a case, the device looks for the available network in the area and selects the proper one based on the decision support algorithm described below. The question arising is how often the system looks for the available networks in the area in order to decide whether it switches into a new one. Since the network searching is an energy-consumed action, the scheduling problem is of a great importance. Factors that influence the scheduling is the average energy spent (per technology) over the residual energy/over the remaining days till the next change and the energy required of a search. Also in regular application the sensor nodes may by default be in sleep mode and they are activated and search for a network when there are healthcare data ready for transmission or request is received by the hospital for a specific measurement.

The emergency nature of the application is a factor that influences the selection. If the application is very urgent for the patient's life, like ECG, and should be repeated every 10 minutes, in such a case the first issue that is examined is the network availability together with the QoS constraints of the application. Thus, the information should be delivered with the minimum loss and delay and energy efficiency is the second priority on the decision system. In case that the patient is having a heart condition and should be monitored regularly, the minimization of the radiation is the first decision factor together with the remaining battery lifetime.

The same decision may be taken for all regular monitoring applications where the energy efficiency may be the first priority and the minimization may be the second in cases where the battery change is not very sufficient.

B. Cost Functions

The Cost Function is the sum of the cost per link. The cost per link is a function depending on the healthcare application (jitter, delay constraints) and the residual energy, weighted by a factor per case

$$C_{Total} = \sum_i C_{link}^i \qquad (3)$$

The QoS factor per connection is:

$$Q_{Total} = \sum_i Q_{link}^i = iQ_{link}^{\min} \qquad \forall i \qquad (4)$$

where

$$Q_{link}^{\min} = \min\ Q_{link}^i \quad \text{for } all\ i\text{'s} \qquad (5)$$

In the following lines a pseudocode is quoted, which describes four main phases (cases) in respect to our decision support algorithm. In addition, Fig.1 depicts the algorithm's flow chart.

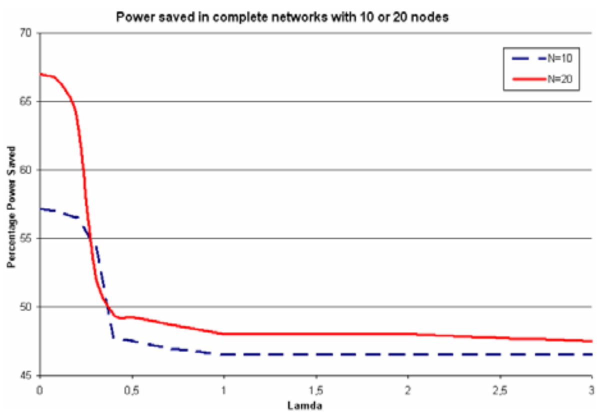

Fig. 2. Power saved in complete networks with 10 or 20 nodes

Case 1 "Emergency – Urgent"

```
Define urgent Biomedical Measurement
Define required information rate, bandwidth
  Check available WPAN/WLAN  technologies
    Check bandwidth, information rate
    Estimate energy efficiency
  Return max QTotal (technology)
end
  Employ Case 4
```

Case 2 "Radiation minimization"

```
while urgent Biomedical Measurement (active)
  employ case 1
else
  Check available WPAN/WLAN  technologies
  Define Biomedical Measurement
      Check bandwidth, information rate
  Return min battery_consumption  (technology)
  end
employ Case 3
```

Case 3 "Seldom Battery Change"

```
while urgent Biomedical Measurement (active)
    employ case 1
  else
    employ Case 2
end
```

Case 4 "Continuous Monitoring"

```
while urgent Biomedical Measurement (active)
    employ case 1
  else
    employ Case 2
end
```

As depicted in Fig. 1, the algorithm is divided in four cases satisfying the cost per link function that depends on the several QoS parameters and constraints. The main target is to provide immediately all the services needed (if supported) in order to transfer the critical amount of the patient's biomedical information. In all other cases the algorithm is capable to providing continuous monitoring services in respect to efficient energy management and radiation minimization. Values in parentheses define the current case and the employed case, decided by the algorithm according to the biomedical information rate needs. Dashed lines correspond to lower-priority case transitions, while solid lines indicate emergency situations.

Fig. 2 illustrates the Percentage Power Saved as a function of edge probability – Lambda (λ) in a complete wireless sensor network containing 10 or 20 sensor nodes. The variable λ shows how dense the network is. Thus, a probability of 0.1 (λ = 0.1) generates sparse networks (allowing more parallel transmissions and hence less power savings). A probability of 0.9 (λ = 0.9) generates dense networks with much better power conserving behavior.

Simulation results (containing 10-20 sensor nodes) showed that power saving in the range from 10% (for sparsely connected networks) to almost 70% (for fully connected networks) could be achieved without affecting the delay-throughput behavior. PAMAS reduces power consumption by almost 50% for high loads and by even more for low loads. However, the main disadvantage of the PAMAS protocol is that it requires a *separate signaling channel*, and therefore requiring more complicated hardware. Conclusively, PAMAS can be useful for delay-critical wireless sensor networks because it does not affect the delay [13].

Fig. 3 illustrates the Energy Consumption (mJ) as a function of message inter-arrival period (s) in a complete two-hop wireless sensor network (with two sources and two sinks).

The comparison is made between the IEEE 802.11-like protocol without sleep, the S-MAC protocol without periodic sleep and the S-MAC protocol with periodic sleep. According to this figure, for the *highest rate* with a 1s inter-arrival time, the wireless channel is nearly fully utilized due to its low bandwidth. *The traffic is heavy* when the message inter-arrival time is less than 4s. In this case IEEE 802.11 MAC uses more than twice the energy used by S-MAC. Since idle listening rarely happens, energy savings from periodic sleeping is very limited. S-MAC achieves energy savings mainly by avoiding overhearing and efficiently transmitting a long message. When the message inter-arrival period is larger than 4s, traffic load becomes light. In this case, the complete S-MAC protocol has the best energy property, and far outperforms IEEE 802.11 MAC.

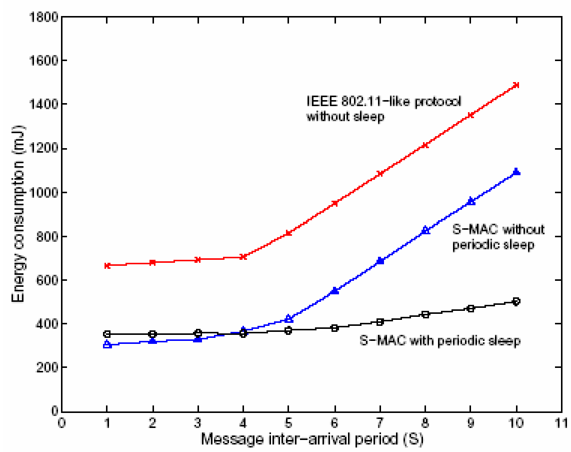

Fig. 3. Energy consumption for different protocols

V. CONCLUSIONS

In wireless sensor networks, which are expected to operate unattended for a long period of time, power conservation is a major issue, since it determines the network lifetime. Several power conservation schemes have been proposed for prolonging the lifetime of the sensor network, which usually take advantage of the sleep mode capabilities of sensor nodes. However, the putting of nodes to periodical sleep introduces a sleep-related access delay that increases with the achieved power conservation. Moreover, the unavoidable idle listening limits the power consumption under low traffic load. Simulation results showed that PAMAS can be useful for delay-critical wireless sensor networks because it does not affect the delay and S-MAC achieves energy savings mainly by avoiding overhearing and efficiently transmitting a long message. For assessment purposes, the complete S-MAC protocol has the best energy property, and far outperforms IEEE 802.11 MAC.

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