Research Issues in Wireless Communications and Networking

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IIUM Press
INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

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Published by:
IIUM Press
International Islamic University Malaysia

First Edition, 2011

Perpustakaan Negara Malaysia Cataloguing-in-Publication Data

Farhat Anwar & Wajdi Al-Khateeb: Research Issues in Wireless Communications Networking

ISBN: 978-967-418-149-9

Member of Majlis Penerbitan Ilmiah Malaysia – MAPIM
(Malaysian Scholarly Publishing Council)

Printed by:
IIUM PRINTING SDN.BHD.
No. 1, Jalan Industri Batu Caves 1/3
Taman Perindustrian Batu Caves
Batu Caves Centre Point
68100 Batu Caves
Selangor Darul Ehsan
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CHAPTER 18

PRACTICAL APPLICATIONS AND DESIGN CHALLENGES OF WIRELESS HETEROGENEOUS SENSOR NETWORKS

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18.1 INTRODUCTION

18.1.1 Conceptual Definition of Wireless Heterogeneous Sensor Networks

Heterogeneous, {hetero + genos 'type', from Greek}, is defined in Oxford Advanced Learner's Dictionary as "consisting of many different kinds of people or things" and defined in Longman Dictionary as "consisting of parts or members that are very different from each other."

The design of interconnected nodes may be heterogeneous or homogeneous with the aim of catering for the design demands and purpose of various wireless applications. The heterogeneity or homogeneity of the interconnected nodes designed is with respect to their ability to sense events, transmit desired sensed data, computing and processing user queries, managing of energy resources and minimizing the complexity of the hardware design. The participating nodes in heterogeneous networks may be different in many aspects. They could have different transmission radius, various kind of sensing units, different hardware power, and different power supply. Nodes with lesser energy resources serve as sensing nodes to collect physical information while nodes with more energy resources serve as data sinks. Heterogeneity could be viewed either in terms of capability or functionality of sensor nodes. In homogeneous networks, all the participating and active nodes are alike in nature and the same transmit power level is used for their operation. These alike nodes are inherently built with the same sensing units to track a single event [5, 9, 10]. Cluster heads and cluster members have different tasks in clustered sensor networks in the course of data delivering to the base station. An example is a tiered sensor network architecture where 802.11 mesh network comprise of high-end nodes, such as Intel XScale nodes which are deployed on a plain WSN field.

In this chapter, A network which comprises of various types of sensors with tunable transmits power level, various sensing units, and various power resources is being refer to as a wireless heterogeneous sensor network. At this juncture, it must be mentioned that this definition does not include wireless networks that comprises of different subsystems and employ various access technologies.

Heterogeneous sensor network is a promising architecture that caters for various applications in the area of environmental monitoring, unobtrusive healthcare, battle field surveillance, biochemical detection, smart home, and industrial monitoring. For example, heterogeneous wireless sensors were employed for future intelligent combat system in the air (Unmanned Airplanes), under the water and on the ground (Unmanned Underwater Vehicles).

A wireless heterogeneous sensor network for biomedical applications will be discussed in the next subsection with the aim of providing a detailed, comprehensive and illustrative explanation.

18.1.2 Heterogeneity of Biomedical Sensor Networks: A Practical Application Example

Wireless Biomedical Sensor Networks (WBSN) is basically heterogeneous in terms of communication units, computation ability and sensing devices. A biosensor network is use for the purpose of large-scale monitoring such as disaster relief or for personal area monitoring in hospitals. The biomedical sensor component are diversified to monitor various physical signals, such as pressure, temperature, intestinal acidity, gastrointestinal images, heart rate, etc. These sensors may be embedded into various mote boards (e.g., TelosB, MicaZ, etc), as they are designed for different purposes and from different manufacturers (Hill, and Culler, 2002 and Johnson, Robert, and David, 2005). The central processing units vary which ranges from powerful laptop CPU to a small SoC chip depending on the kind of product or manufacturer which led to the diversification of its computational ability. In order to ensure the inter-operability and inter-communicability of the biomedical sensors, we make an assumption that the radio-frequency transceivers are configure with the same communication protocol. Hence, WBSN usually is featured with heterogeneity and require a holistic consideration for system optimization (Ren, Meng, and Chen, 2005).

The importance of WBSN is self-explanatory. Wireless heterogeneous biomedical sensors network will significantly assist in enhancing the performance of medical care. It gives room for long-term wireless health monitoring and the patients or the aged are occasionally permitted to roam about in the building. This is very useful when nursing a contagious patient in avoiding personal contact in a big hospital. The end users such as the physicians concerned or even the patient themselves can retrieve the health information collected from the web data base where it is stored as a health record (Johnson, et. al., 2005 and Ren, et. al., 2005). While delivering the data to a database system for long-term storage, it sent an alert of any abnormalities in the physiological condition of the patient to the healthcare professionals in charge. This reduces the time spent by the health care professionals on routine checkup, consequently, reducing the cost of medical care. Emergency can easily be attended to with the help of its real-time monitoring. An important clue to the state of the health of the patients can be obtained from the data gathered by the sensor network such as the monitored level of blood sugar, the heart beat, temperature, etc for a diabetic patient. Unlike wired monitoring system, the WBSN can be used even when people are in motion for long-term and continuous monitoring. Furthermore, the coordination of the networked nodes can facilitate the operation of higher-level medical tasks (Hill, et. al., 2002 and Ren, et. al., 2005).

Typical application scenarios of WBSN are various Smart home health monitoring. For instance, patients with chronic disorders and older people can live on their own longer with the help of the WBSN. Smart ward in the hospital reduce the time of routine checkup and emergency can be urgently attended to with the help of its real-time monitoring (Ross, et. al., 2004 and Ren, et. al., 2005). Besides, personal contacts can be avoided for the nurses in a contagion ward to reduce the possibility of being infected. WBSN can also be utilized for tracking and monitoring the state of the health of an Athlete by monitoring and tracking his pulse and respiration rate, heart beat etc via sensors and sending the data obtained to the base station which is usually a computer for further processing and analysis. In addition to this, WBSN can be used to capture real-time vital signs from patients in a moving ambulance in situation where an emergency medical care is needed and relay the data to a handheld computers carried by physicians for pre-hospital diagnosis (Malan, Fulford-Jones, Welsh, and Moulton, 2004 and Ren, et. al., 2005). A diagrammatic representation of this scenario is shown in Fig. 18.1.

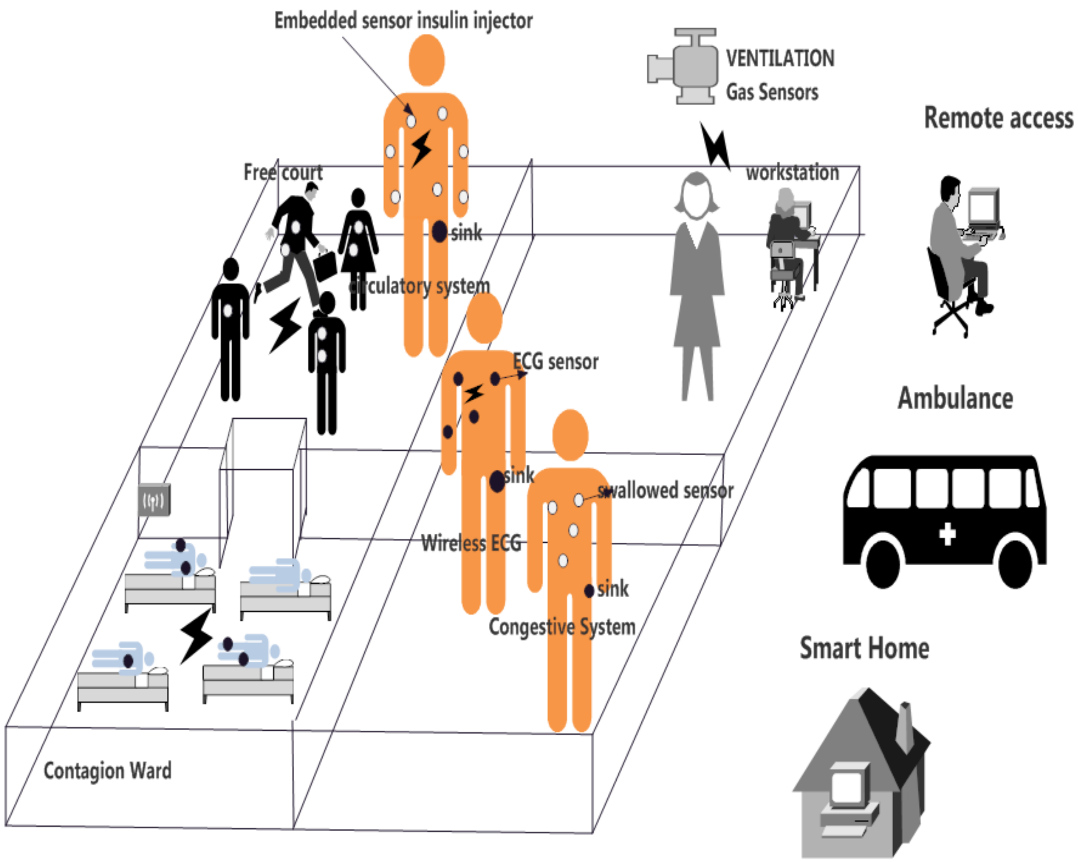

Figure 18.1: Typical Scenarios of WBSN Applications

18.2. DESIGN CHALLENGES

As a focused research area, Wireless Sensor Networks (WSN) has achieved fruitful results, such as embedded operation system development, node platform manufacturing and network protocol algorithms (Akyildiz, Su, Sankarasubramaniam, and Cayirci, 2002). Current researches are focusing mainly on networks which consist of identical sensors with equal sensing, computation, power and communication capability. Nevertheless, heterogeneity is an important feature for most wireless sensor networks. An insight which propels and motivates this work was the fact that most existing technique in WSN cannot be applied directly to heterogeneous wireless sensor networks.

The general challenges in terms of sensor networks are well known as low power constrains, limited computation, robustness, fault tolerance, scalability, densely deployment, security and latency. Moreover, the major requirements and concerns of WHSN are as follows:

1. *Reliability*: The first major challenge is ensuring that information reliably reaches its destination. Systemic design that relies on various aspects such as reliable wireless communication between sensor nodes, efficient computation in each sensor node, stable software programming, etc are the main determinant of the reliability of WHSN.

2. *Decentralization*: Distributive and adaptive operation based on perceived statistics is needed due to the decentralized nature of sensor nodes.

3. *Lightweight Protocols*: Lightweight protocols are desirable for network maintenance, self-organization, data collection and dissemination.

4. *Clustering*: Cluster head and cluster member having different capability and performing different function is a typical display of clustering behavior in heterogeneous sensors. Therefore, it is very essential to ensure efficient network operation in the hierarchical architecture.

5. *Network dynamics*: Network dynamics is caused either by node failure or sleep or motion. Hence, in order to cater for the dynamically changing networks an adaptive algorithm is needed.

6. *Energy-Efficient Communication*: In order to achieve an acceptable connectivity, it is most desirable that the transmit power of nodes should be minimized for the purpose of long-term monitoring and minimum interference. Nodes negotiate their transmission power to minimum with the aid of energy aware protocol.

7. *Scalability*: Scalability is an important feature in the design of heterogeneous sensor networks.

8. *Constrained and Diversified Resource*: The resource conditions in WHSN such as the scarce wireless channel bandwidth and the limited energy supply are stringent. Meanwhile, the resource conditions are quite different for various wireless devices, which will lead to power diversity, rate diversity, energy diversity and load diversity.

18.3. OPEN PROBLEMS FOR FURTHER RESEARCH

With respect to the challenges mentioned above, there is a growing concern about resource allocation in heterogeneous sensor networks, specifically focusing on the power efficient topology optimization problems. Primarily, this section aimed at highlighting the open research areas where further research can be carried out:

- How to model the topology control problem of heterogeneous sensor network theoretically, given the diverse resource constraint;
- How to reach network-wide optimal operation point through power scheduling, a decentralized decision making process of heterogeneous sensors;
- How to implement the resource allocation algorithm efficiently in practical applications;
- How to provide location information for topology management during the process of dynamic power scheduling;
- How to build up an energy-efficient heterogeneous sensor network for biomedical applications.

18.4. CONCLUSION AND RECOMMENDATIONS

With the above mentioned problems in mind, In order to examine the distributive power control for optimizing the topology there is need to employ a theory of game. In the theory of game topology control, the heterogeneous sensors also known as players in the theory of game schedule their power being transmitted refer to as action so as to attain individual utilities also refer to as pay off. The utility function is being studied by this approach with the aim of attaining a desirable success frame rate and node degree while reducing the cost of increasing power. In addition to this, Nash equilibrium in static game is the starting point in such strategy and its existence is proved in power control game. A realistic incomplete-information dynamic game played is also recommended for heterogeneous sensor in WHSN, where Bayesian formulation in both dynamic and static game are used to get a perfect-Bayesian-equilibrium need to be studied.

A practical application where a distributed topology algorithm control is employed is also recommended with the aim of ensuring power efficiency and reliability. A centralized controller is essentially needed in order to obtain the global network graph was the existing approach used by researchers to control topology. A novel theoretical game model that will yield a decentralized optimization to control topology is recommended to be designed. A mathematical game analysis is the backbone on which such approach is built on which led to the two solution implementation concepts provided. A derivation from Nash Equilibrium of static game model known as the NEPow scheme is one of the strategy suggested. The NEPow scheme is very suitable in scenarios using homogeneous (same type) of sensor nodes. Also, another strategy derived from Bayesian Nash Equilibrium of incomplete-information dynamic game model known as the BEPow scheme was also recommended. The BEPow scheme is suitable in scenarios where there are sensor nodes having different degree of power levels that is heterogeneous types of sensor nodes. Furthermore, a theory of game is recommended to analyze individual sensor nodes decision-making process and more so, to ensure achieving the suitable and desired utility, the reachable equilibrium should also be analyzed.

The topology management information position is being provided by the signal strength (RSSI), this significant tasks being carried out by the RSSI call for addressing the inconsistent signal strength (RSSI) issue first which is caused as a result of power tuning. Incorporated into the localization process is the changing transmitting power which serves as a dynamic evidence for using particle filter. In addition to this, multiple powers scheduling in the context of WHSN is used as the bases for examining localization problem. The particle filter is also desirable to first generate a number of hypotheses, after which it should then predict forwarded particles from transition model, and use the RSSI-measurement to weight them which are important sampling under different power settings is also recommended. An iterative prediction, weighting and re-sampling processes is used in the design of particle filter so as to obtain a posterior belief of node position. It is also suggested that the particle filter should be capable of turning the tune multiple-power for data fusion process where necessary. The challenges faced in monitoring spatial constraints for biochemical materials should also be put in consideration in designing a non-parametric particle filtering approach which aims at probabilistically determining the trajectories of moving nodes. Two asymmetric observation models is recommended to be introduced that will incorporate cardioid-shaped patterns measured response of ultrasound sensors.

Heterogeneity is the most spectacular features of Wireless Biomedical Sensor Network (WBSN), it shows great potentials in enhancing medical performance by incorporating smart sensors, network technologies and wireless communication. The major design challenges and requirements in WBSN are systematically analyzed and fully elucidated in this chapter. The flat tree architecture and network protocols are also explore in this chapter, Recommendation on the preliminary solutions for the WBSN in a hospital environment is made. The design of a compact sensor platform for biomedical applications is one of the important recommendation made and also evaluating its signal radiation efficiency. Conclusively, a test-bed for patient monitoring system is being recommended in this chapter that will integrate the functionalities of physiological information acquisition, data publishing and transmission.

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