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A Study on Distributed Self-Reliance Wireless Sensing Mechanism for Supporting Data Transmission over Heterogeneous Wireless Networks

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Abstract

The deployment of geographically distributed wireless sensors has greatly elevated the capability of monitoring structural health in social-overhead capital (SOC) public infrastructures. This paper deals with the utilization of a distributed mobility management (DMM) approach for the deployment of wireless sensing devices in a structural health monitoring system (SHM). Then, a wireless sensing mechanism utilizing low-energy adaptive clustering hierarchy (LEACH)-based clustering algorithm for smart sensors has been analyzed to support the seamless data transmission of structural health information which is essentially important to guarantee public safety. The clustering of smart sensors will be able to provide real-time monitoring of structural health and a filtering algorithm to boost the transmission of critical information over heterogeneous wireless and mobile networks.

Keywords: *wireless sensor networks (WSNs), LEACH, data transmission, sensing mechanism, filtering algorithm.*

1. Introduction

Structural health monitoring (SHM) systems for SOC public infrastructures have evolved from the installation of permanent array of sensors capable of measuring and/or gathering structural health information to the deployment of geographically distributed wireless sensor networks (WSNs). There have been various efforts to optimize the transmission of structural information which is critical for the management of structural health of SOC public infrastructures. Seamless and real-time transmission of structural information is of paramount importance in the safety of the users of such infrastructures.

The deployment of WSNs has emerged to compensate the issues of inflexibility and scalability for the installation of the permanent array of sensors. It has also addressed other limitations of wired transmission

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schemes as to data acquisition and data management concerns. WSNs refer to the deployment of geographically distributed autonomous wireless sensors capable of collecting physiological and environmental conditions. WSNs for SHM systems have been deployed in various architectures aiming to optimize the routing and transmission of structural information [1][2][3]. This includes mobility management protocols, peer-to-peer data transmission techniques, centralized management architectures, and distributed mobility management approaches. Each technique was developed to address specific issues concerning the increasing amount of structural information, routing, and managing data traffic during transmissions [4].

This paper deals with the analysis of a wireless sensing mechanism to support a seamless data transmission in a structural health monitoring system over the heterogeneous wireless and mobile networks. The distributed management approach was utilized to optimize the routing, control, and management of data traffic among the wireless and mobile nodes of the SHM system. Then, a sensing mechanism utilizing a LEACH-based clustering and routing algorithm has been analyzed to support the seamless data transmission for the SHM system and a filtering algorithm has been incorporated to further enhance its efficiency.

2. Overview of Wireless Sensor Networks

WSNs refer to a collection of spatially dispersed sensing devices that are capable of monitoring and measuring physiological and environmental conditions [5]. The collected data from autonomous sensing devices will then be transmitted, organized, and managed at a central or main location or sink for observation, analysis, and processing. Physiological and environmental conditions that can be monitored and measured by WSNs include motion, pressure, temperature, vibration, sound, wind speed, humidity, heat levels, pollution levels, visibility, and so on. Data communications between nodes are bi-directional whereby sensor node activities can be controlled. Each sensor node is typically comprised of several parts: a radio transceiver, a microcontroller, and an energy source. The radio transceiver includes an internal antenna which is capable of transmitting and receiving data signals. The microcontroller is an electronic circuit used for interfacing with the sensors, while the energy source can be a low power battery or an embedded form of energy harvesting circuitry. The collected physiological and environmental data will be passed by the sensing nodes to a central node called the base station or sink that acts as an interface between users and the sensor network as indicated in Figure 1. The user can get information from the sensor nodes through the process node interrogation and gathering results from the base station. In the figure, the dashed arrows indicate the communication lines from the sensor at the edge of the sensing domain towards the base station or sink which will then be transmitted via the Internet and accessed by the user.

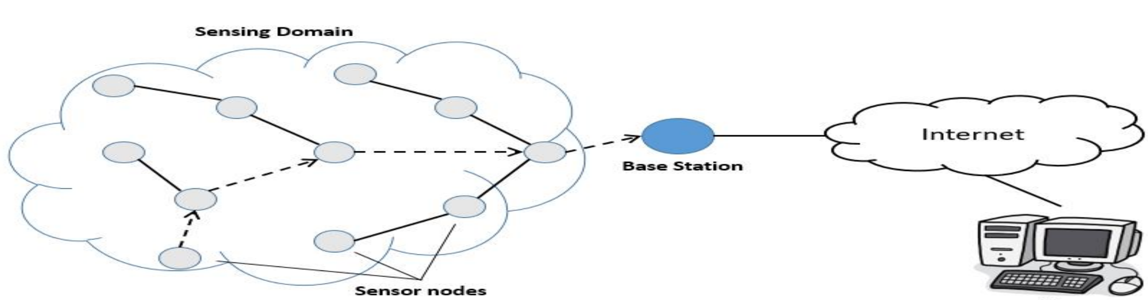


Figure 1. A typical Wireless Sensor Network Architecture

WSN is typically comprised of hundreds or even thousands of sensor nodes. These sensor nodes are capable of self-organizing into a suitable network configuration and communicate through a multi-hop approach using radio signals. After self-organization, they continuously collect information on their specific functionalities and also respond to interrogations from the control programs at remote areas operated by users via the base station or sink [5][6]. WSN architectures can use network topologies such as star network (i.e., single point-to-multipoint), mesh network, hybrid star-mesh network, and advanced multi-hop wireless mesh network. Data transmission between the sensor nodes can utilize routing or flooding algorithms [6][7]. Other routing algorithms and protocols include gossiping, sensor protocols for information via negotiation (SPIN), low-energy adaptive clustering hierarchy (LEACH), power-efficient gathering in sensor information systems (PEGASIS), and so on. In this paper, WSNs were utilized in boosting the level of SHM systems in order to monitor the movement within buildings and infrastructure such as tall buildings, bridges, flyovers, embankments, tunnels, national highways, dams, etc.

3. Distributed Wireless Sensor Architecture for Seamless Data Transmission Scheme

A seamless and real-time data transmission scheme is essentially important for SHM systems as structural and environmental information is critical in managing SOC public infrastructures and guarantees the safety of the public. To warrant such seamless and real-time data transmission, a robust mobility management must be incorporated to provide an efficient mobility support and guarantee an optimized transmission of critical information [8]. In this regard, the network-based distributed mobility management (DMM) architecture [9] has been analyzed to provide a robust and efficient mobility support and address the drawbacks of the standard mobile internet protocol (MIP) [10] that concerns scalability, locality, load balancing, packet loss rate, signaling overhead, complexity, fault tolerance, route optimization, and so on.

The network-based DMM approach is an emerging mobility management paradigm which is based on the proxy mobile Internet protocol version 6 (PMIPv6) where the mobility management was pushed to edge of the network, that is, it employs mobility anchors in the access router (AR) level which is closer to the users. It was developed aiming to address the problems incurred by the centralized mobility management concerning the handover operations [9][11]. The network-based DMM approach is considered as a partially distributed solution where data and control planes were separated. It includes a centralized control plane kind-of Local Mobility Anchor (LMA) which is a central node capable of storing the mobility sessions of the mobile nodes (MSs) and a distributed data plane where only the edge access routers are handling the data forwarding [12].

The partially distributed network-based DMM support seamless data transmissions in SHM systems include the following main entities:

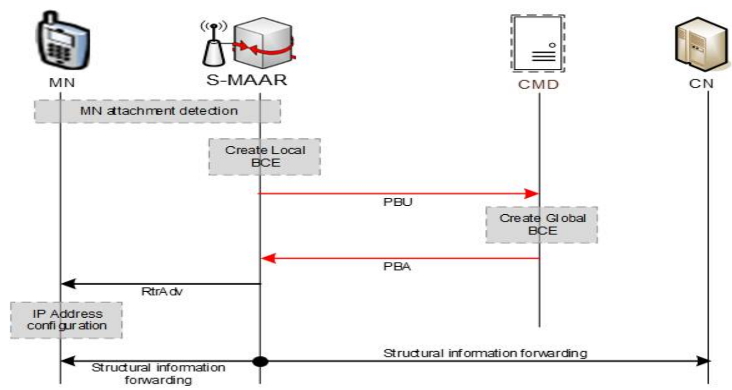
(1) The mobility anchor and access router (MAAR) which is located one internet protocol (IP) hop from the MN and is responsible for forwarding data packets to and from IP networks. The access router (AR), mobile access gateway (MAG), and local mobility anchor (LMA) functionalities are focused based on each MN or each prefix. An IP prefix is assigned and anchored by the MAAR to each of the attached MN. The MAAR is classified into the following:

- the serving MAAR (S-MAAR) where the MN is currently attached to; and
- the anchor MAAR (A-MAAR) which is the previously visited and anchoring MAAR.

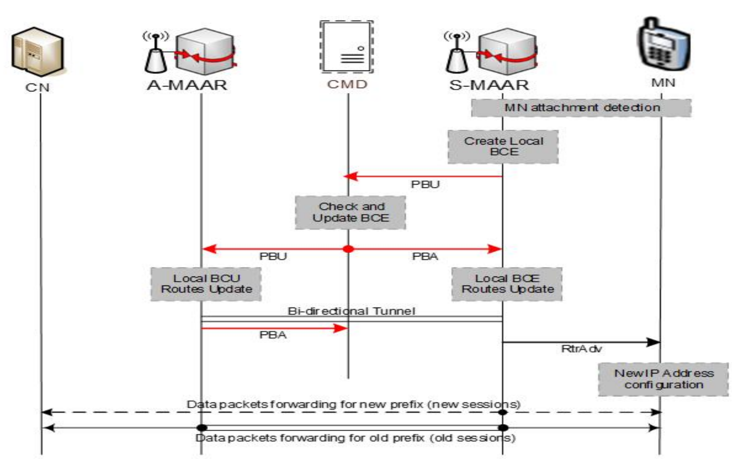
(2) The centralized mobility database (CMD) which acts as the central node in storing the mobility sessions (i.e., the binding cache entries (BCEs)) of all the MNs positioned within the domain. The

CMD is not traversed by the data packets and it acts as the LMA for the control plane.

Figure 2 depicts the initial registration and handover operations of the partially distributed network-based DMM support for a seamless data transmission in SHM systems. When the MN approaches the S-MAAR, the latter registers the MN at the CMD through a proxy binding update (PBU) and proxy binding acknowledgement (PBA) handshake, as shown in Figure 2(a). During the handover, a PBU is sent by the S-MAAR to the CMD notifying the attachment of the MN. Then, the CMD sends out instructions on establishing the proper routing configuration to both S-MAAR and A-MAAR. The handover operation where CMD acts as PBU and PBA proxy is depicted in Figure 2(b).



(a) Initial MN Registration



(b) Handover Procedure

Figure 2. Partially Distributed Network-based DMM Operations

The partially distributed network-based DMM limits the traffic overhead in terms of encapsulation while improving the scalability and robustness of the data transmission scheme. These advantages guarantee the seamless transmission of structural and environmental information among the SHM system nodes which is essentially important for managing SOC public infrastructures.

4. Wireless Sensing Mechanism to Support a Seamless Data Transmission

This paper deals with the analysis of a wireless sensing mechanism in supporting seamless data transmissions in SHM systems for SOC public infrastructures over the heterogeneous wireless and mobile networks. It is designed aiming to address the numerous social issues concerning the public safety on utilizing the SOC public infrastructures. The system is mainly comprised of spatially dispersed autonomous smart sensors that are capable of monitoring and measuring physiological and environmental information related to the health and usage of the infrastructure. To fully optimize the seamless transmission of structural information in SHM system, a wireless sensing mechanism has been analyzed in such a way that only the critical or essential information will be passed by the smart sensors and leave out other unrelated signals. In this way, data traffic can be minimized as smart sensors typically transmit periodic physiological measurement signals to its corresponding base station or sink. Thus, the smart sensing device must be capable of performing a filtering algorithm to the large amount of collected and measured raw data before they are passed to the sink and to the SHM system server for further analysis and processing. The filtering algorithm will extract critical signals (e.g., important structural health data, triggering events such as vehicular accidents, scour, and strong level of vibrations caused by earthquakes) by separating the insignificant signals (e.g., noise signals, periodic normal readings). This results into an optimized data traffic flowing across the wireless SHM network improving the system's robustness and efficiency.

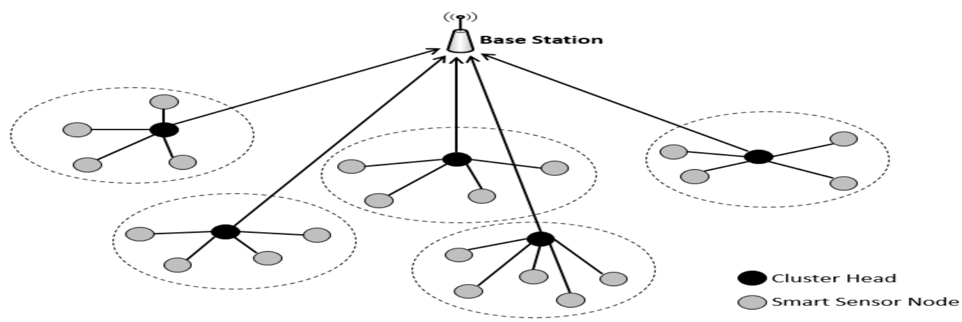


Figure 3. LEACH-based Clustering and Routing Algorithm

Moreover, the system takes advantage of the features of low-energy adaptive clustering hierarchy (LEACH) routing algorithm [13] to collect and forward the filtered signals from the smart sensing devices to the base station or data sink. The LEACH protocol aims to provide network lifetime extension, reduced energy consumption for each smart sensing device, and usage of data aggregation in reducing the number of communication messages or signaling overhead. It adopts a hierarchical approach in organizing the wireless smart sensors into a set of clusters managed by a designated cluster head. The cluster head is responsible for the periodic data collection from the cluster members, aggregation of the collected data to remove redundancy among correlated values, forward the aggregated data to the base station or sink through a single hop, create and broadcast a time division multiple access (TDMA)-based schedule for cluster members (i.e., each smart sensing device will be assigned a time slot for transmission). The LEACH-based clustering and routing algorithm is depicted in Figure 3.

The LEACH protocol clustering operations are divided into two phases, namely, the setup phase, and the steady-state phase [14]. The setup phase aims to form a cluster and assign a smart sensor node with the maximum energy as the cluster head. On the other hand, the steady-state phase deals with data collection, aggregation, and transmission of aggregated data to the base station or sink. In addition, to reduce the probability on the occurrence of collisions among smart sensors within and outside the cluster, and minimize the interference between clusters, LEACH nodes use a code-division multiple access (CDMA)-based scheme such that each cluster uses a different set of CDMA codes for communication. The wireless sensing mechanism process is depicted in Figure 4. The system starts with setting up the clusters for wireless smart sensing devices.

This process involves the selection of cluster heads for each cluster, that is, the sensor node with the maximum energy. Then other smart sensing devices registers with the cluster head to form or create a cluster.

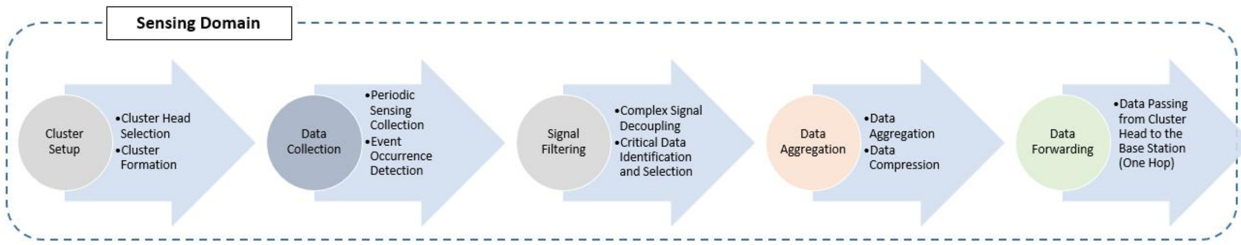


Figure 4. Wireless Sensing Mechanism Process

As soon as clusters have been formed, smart sensing devices starts collecting periodic measurements and readings based on their specific functions (e.g., pressure sensors, wind speed meters, temperature sensors, etc.). Other signal detection from unwanted events will also be collected.

The collected raw data signals will be the input to the filtering algorithm where the insignificant data will be separated from the critical or essential information. Thus, only significant information will remain for further processing and will optimize the data traffic to be transmitted. The periodically sensed or measured signals that are insignificant will also be disregarded. Then, the filtered significant structural and environmental information will be aggregated and compressed before it will be forwarded to the base station or sink which is located in only one-hop distance from the cluster heads.

Whenever the structural and environmental information goes out from the sensor domain's base station, it enters the distributed mobility domain where the routing will be distributed across the mobile anchors which were deployed at the edge of the wireless networks and closer to the users. The CMD determines the best route to which the data traffic flow will be optimized through checking the bandwidth of every transmission route. The data traffic will only traverse the access routers (i.e., members of the data plane) distributed over the heterogeneous wireless and mobile networks as directed by the CMD which has a centralized control of all data transmissions. This process guarantees an efficient and seamless data transmission for SHM systems in SOC public infrastructures.

5. Conclusion

This paper has presented an analysis of wireless sensing mechanism to support a seamless data transmission over the heterogeneous wireless and mobile networks. The designed data transmission scheme aims to uplift and optimize the structural health monitoring concerns for SOC public infrastructures. The sensing mechanism employs a LEACH-based clustering technique for smart sensor node formation and collection of structural and environmental information. Then, a filtering algorithm capable of extracting the significant and essential information to minimize the data traffic in the transmissions has been incorporated. Furthermore, the data and control infrastructures have been separated to further optimize the transmissions of such significant and essential information across the SHM system entities.

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