A Study on the Convergence of Mobile Networks and WMSNs for Structural and Environmental Monitoring

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Abstract

This paper deals with the convergence of mobile computing and wireless multimedia sensor networks (WMSNs) in order to enable an effective and efficient structural health monitoring (SHM) of bridges as part of the social overhead capital (SOC) public infrastructures. This convergence makes full advantage on the features of both mobile computing to allow seamless mobility and distributed data flow, and WMSNs to allow a robust structural and environmental monitoring. The distributed mobility management support enables the balanced and real-time transmission of structural and environmental data collected by the multimedia sensors among the mobile terminals. That is, the SHM information flow will be distributed among the corresponding network gateways, while the overall control of node mobility and data flow will be managed by a central network entity. Moreover, multimedia sensors can enable a more sophisticated gathering of such structural and environmental data, thus, more reliable traffic and environmental conditions can be conveyed to guarantee public safety.

Keyword : mobile computing, wireless multimedia sensor networks (WMSNs), structural health monitoring (SHM), distributed mobility management (DMM), social overhead capital (SOC)

1. Introduction

There have been significant social issues regarding the social overhead capital (SOC) public infrastructures such as structure damages and failures caused by natural disasters and accidents since the past. SOC public infrastructures include railways, national roads and expressways, bridges, tunnels, dams, high rise buildings, communication towers, electrical grid, ports and airports, and others. Structural damages and failures can be caused by natural calamities such as earthquakes, typhoons, excessive exposure to extreme heat, flooding, and other environmental disturbances. Other factors such as extreme or combination of live loads, structure age, and poor structural maintenance can also significantly contribute into damages and failures of SOC public infrastructures. For example, the September 2016

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earthquake in Gyeongju, South Korea have resulted to temporary shutting down of a motor plant, a power station, and subway train operations [1]. In November 2017, a 5.4 magnitude earthquake have struck Pohang, South Korea and caused significant infrastructure damages in the southern port of the city [2]. Based on the initial assessment by the Ministry of the Interior and Safety, there were 2,165 damaged private properties that include 1,988 private houses. Schools across the region were also affected, and damages were reported at 79 public offices and parks, 23 port facilities, 7 roads, 90 shops, 77 factories, and 11 bridges [3].

Structural damages, failures and collapses were generally caused by design and construction errors, age and deterioration, and triggering events such as vehicular accidents, scours, and natural calamities such as earthquakes, typhoons, and heavy rains. In this regard, there should be initiatives on infrastructure redesigns and stronger inspection and monitoring programs for such SOC public infrastructures to ensure public safety. Early structural monitoring systems were generally visual-based inspections which were limited to accessible locations only, and were expensive and labor intensive.

Various efforts have been initiated to strengthen SHM systems but its functionalities were still limited into indirect sensing approaches, scalability, data and decision-making capability, and mobility. Structural sensors that were used cannot sense the damage and were also vulnerable to failures. In addition, manual processing were still used in the management of data collected from these sensors. Moreover, the SHM systems were not able to provide decision-making support for end-users regardless of how sophisticated the data gathering. Thus, a real-time and continuous structural health monitoring that is able to provide the public with an essential information for better decision-making (e.g., real-time traffic condition) has become an essential solution for safeguarding the SOC public infrastructures to guarantee public safety. The proposed SHM system for SOC public infrastructures will be based on the convergence of mobile networks and wireless multimedia sensor networks in order to provide a more efficient monitoring of structural health, environmental conditions, and real-time traffic updates that will be beneficial for the decision-making of the public and can guarantee their safety. The distributed mobility management allows a balanced data flow for the gathered structural health, environmental conditions, and traffic conditions. The WMSNs allows preprocessing of the gathered data which can limit the load of network infrastructure of the SHM system.

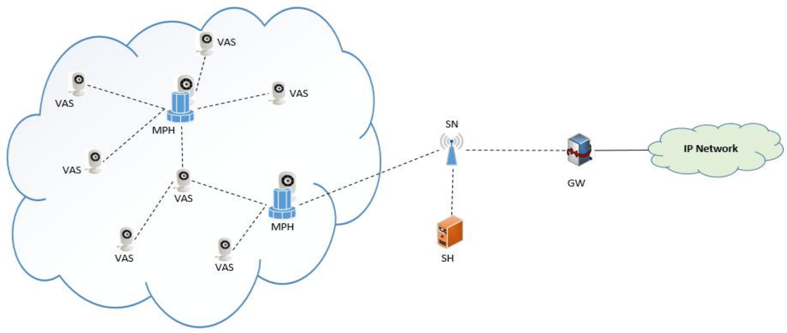
The rest of this paper is organized as follows: Section 2 provides the overview of the wireless multimedia network systems; Section 3 explains the convergence between mobile networks and wireless multimedia sensor network systems; the proposed DMM based structural health monitoring system has been outlined in Section 4; and the concluding remarks in Section 5.

2. WMSNs for Structural Health Monitoring

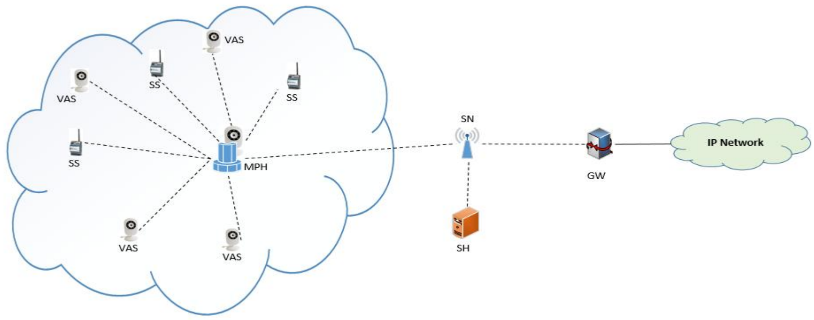
Wireless sensor networks (WSNs) have been widely adopted in many SHM systems that combine features of sensing, computations, and communication. Wireless sensors can be densely installed geographically on SOC public infrastructures (e.g., bridges) to sense and gather the data and conditions of the surrounding environment and transmit it into a processing and more potent node [4]. Recently, low-cost hardware components that were able to gather multimedia data from the environment have become increasingly available. That is, sensors that were also capable of retrieving images, audio and video were made available to provide a more sophisticated structural and environmental monitoring for SOC public infrastructures. These wirelessly interconnected devices were collectively called wireless multimedia sensor network (WMSN) and allows not only the retrieval of scalar sensor information but also able to gather multimedia information [5]. WMSNs were capable of retrieving scalar data (i.e., environmental conditions such as pressure, temperature, water levels, wind speed, etc.) and multimedia streams (i.e., audio and video) [6]. It can retrieve, store, process in real-time, correlate, and merge multimedia contents to provide more intricate SHM functionalities. Its integration with the Internet can allow online processing of retrieved multimedia information through the combined technologies of communications and networking, signal processing, computer vision, and control. The types of nodes and their functionalities in SHM system for SOC public infrastructures were outlined in [Table 1] [6][7].

[Table 1] Types of Nodes in WMSN

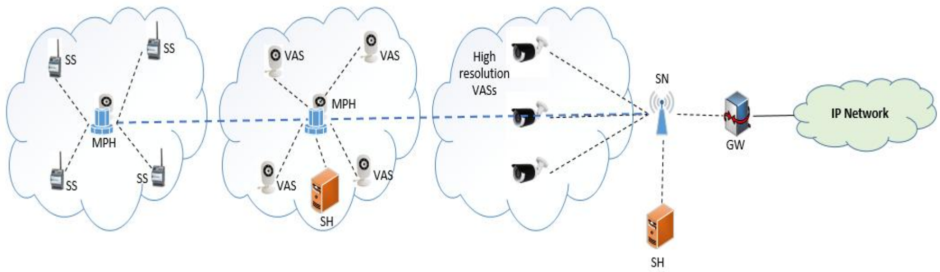
WMSN Node	Functions
Video and Audio Sensors (VAS)	VASs retrieves still images, audio, and video information of the surrounding environment.
Scalar Sensors (SS)	SSs retrieves physical characteristics of the environment such as pressure, motion, temperature, wind speeds, water levels, and humidity.
Multimedia Processing Hub (MPH)	This node receives aggregates the gathered information by the individual VASs and SSs. They contain large computational resources and able to pre-process the sensed information. One major function of these nodes was to perform a filtering algorithm that separates critical structural and environmental information from insignificant signals. This is essential to reduce the dimensionality and volume of data transmitted to the SNs and SHs.
Storage Hub (SH)	SHs allows the retrieved data to be stored for further processing. It is also used to provide the history of retrieved signals that may be useful for future references.
Sink Node (SN)	SNs performs more intricate processing of the sensed structural and environmental information. They are responsible for packaging high-level user queries to network-specific directives.
Gateway (GW)	GWs provide connectivity to the internet protocol (IP) networks. This nodes enable online processing of SHM information.



(a) Single-tier Flat WMSN Architecture



(b) Single-tier Clustered WMSN Architecture



(c) Multitier WMSN Architecture

[Fig. 1] Architecture of WMSNs

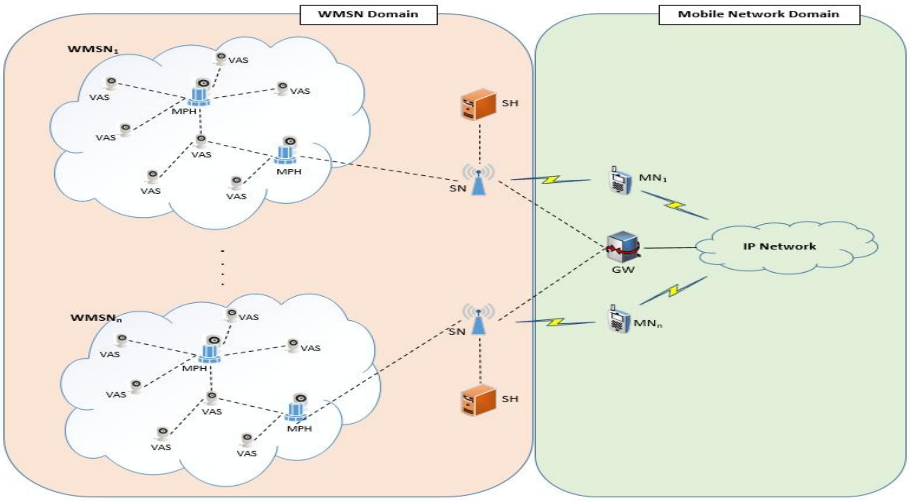
The architecture for WMSN were divided into three categories as shown in [Fig. 1]: Single-tier flat architecture, Single-tier Clustered architecture, and Multitier architecture. The single-tier flat WMSN architecture contains the deployment of homogeneous multimedia sensor nodes that were capable of the same sensing, computational and communication capabilities, and functionalities. For example, all of the sensing devices were comprised of video and audio sensors (VASs). The sensor nodes retrieve structural and environmental information and relays them to the SN through the MPH as shown in [Fig. 1(a)]. On the other hand, the single-tier clustered WMSN architecture contains the deployment of heterogeneous multimedia sensor nodes. That is, a cluster of nodes can be comprised of both SSs and VASs and relays the sensed structural and environmental information to its cluster head called MPH. The MPH performs pre-processing and forwards the filtered structural and environmental information to the SN as shown in [Fig. 1(b)].

The multitier WMSN architecture shown in [Fig. 1(c)] deploys a layered cluster of multimedia sensors. The first layer were deployed with SSs to perform structural and environmental monitoring and gathers data such as pressure, temperature, wind speed, water levels, motion detection, and others. The second layer were deployed with VASs to perform object detection and object recognition. The third layer can be deployed with high-resolution VASs to perform object tracking. Each layer relays their sensed structural and environmental information its cluster head called MPH for processing and transmission into higher layers. The scalar sensors in the first layer are always active and periodically transmits sensed information from its surroundings to its corresponding MPH. The MPH then pre-process the retrieved information and transmits only critical structural and environmental information will be transmitted to the SN. The MPH also triggers the second layer VASs if there’s a need for its functions.

3. Convergence between Mobile Networks and WMSNs for SHM Systems

The integration of mobile networks and WMSNs can be beneficial to SHM of SOC public infrastructures. Mobile networks can enable the optimization and improvement of the overall system performance of SHM network infrastructure while the WMSN enables a more intelligent sensing of structural and environmental information. The convergence of mobile networks and WMSNs allows the decoupling of data and control planes wherein the sensor nodes consists the data detection while the gateways consists the mobile terminals and control plane. The mobile network can directly control and manage the sensor nodes which enable them to choose the optimal transmission path in order to route the SHM data traffic. The architecture of the converged mobile networks and WMSNs is depicted in [Fig. 2].

The collected structural and environmental data from the sensor nodes will be forwarded to the MPH for pre-processing before it can be routed to the IP network through the SNs and GWs. That is, only critical structural and environmental information (e.g., above threshold information) can be conveyed by the MPH to optimize the flow of SHM data traffic. Then, the end users of mobile nodes (MNs) can receive decision-making supported SHM information through the IP network. The WMSNs will be responsible for data collection and forwarding of structural and environmental information which comprises the data plane for the SHM system. The mobile network consists the control plane of the SHM system and manages the operation of WMSNs such as directing the SHM data traffic flow as well as managing the mobility of mobile nodes.



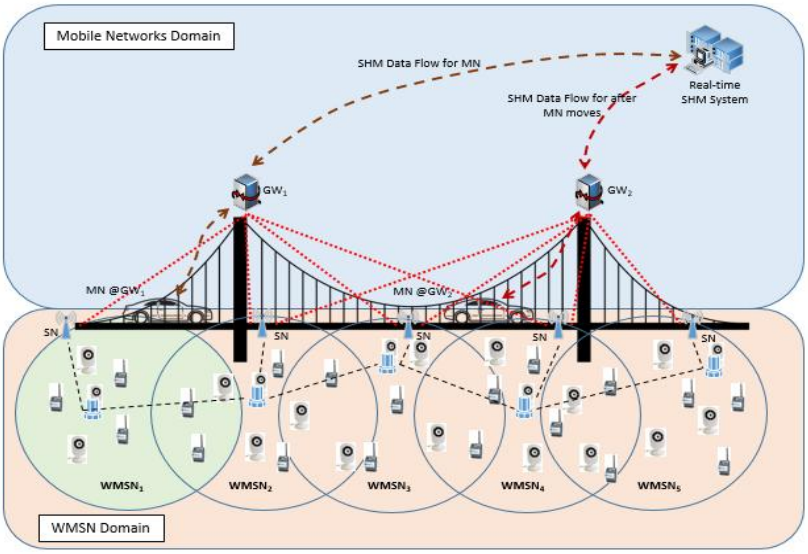
[Fig. 2] Architecture of Converged Mobile Networks and WMSNs for SHM Systems

4. DMM based Structural and Environmental Monitoring

The convergence of mobile networks and WMSNs allows the decoupling of data and control planes of SHM systems. That is, the wireless sensors will be responsible for data collection and the routing structural and environmental information while the GWs in the mobile network will be responsible for coordinating and managing the network paths. The deployment of the converged mobile networks and WMSNs on a bridge infrastructure is depicted in [Fig. 3].

The deployment of the network for SHM is self-organized into three distinct layers of distinct multimedia wireless sensors. The first layer is comprised of always active scalar sensors which are capable of monitoring and detecting unusual triggering events (e.g., above threshold structural and environmental information) in SOC public infrastructures. The second layer is comprised with smart audio and video sensors that are capable of identifying objects within their respective field of views.

The third layer is comprised with high-resolution audio and video sensors that are capable of tracking the identified objects by the second layer sensors through the computation of their location and moving paths. The first layer sensors actively and periodically monitors the environment and triggers the second layer sensors whenever there are critical signals detected and there will be a need for the tasks of higher layer multimedia sensors. The second layer camera sensors then identifies the objects detected by the first layer sensors and triggers the third layer high-resolution video and audio sensors for object tracking.



[Fig. 3] DMM based Structural Health Monitoring System

The distributed mobility management support [8][9] for the mobile networks will be utilized to manage the mobility of mobile nodes in the SHM system. The management of the of the collected structural and environmental information will be distributed among the multiple installed management systems (GWs) that manages and monitors each area within the SOC public infrastructure. Each GW is responsible in independently controlling and monitoring a geographical region or domain [8][10]. Continues and real-time traffic conditions, weather updates, environmental disturbances, and unusual structural conditions can be accessed by the mobile nodes (i.e., moving vehicles) as they roams within the SHM domain. Seamless connectivity for mobile nodes can be provided as its registration is automatically configured by the serving GWs as it moves along its respective domains. The handovers will be performed by the GWs relieving the mobile nodes with the responsibility of initiating the handover signaling processes. The DMM support for the SHM network optimizes the routing of SHM information through controlling the data traffic paths by calculating best possible route for SHM information transmission.

5. Conclusion

This paper deals with the integration of mobile networks and wireless multimedia sensor networks for structural health monitoring of SOC public infrastructures specifically designed for bridges. The convergence of mobile networks and WMSNs enables an optimized routing of SHM information as well as more sophisticated measurement of structural and environmental information. WMSNs can provide more intricate and effective monitoring of SOC public infrastructures, thus, public safety can be guaranteed. The DMM support enables a balanced SHM data traffic flow among the distributed network components allowing a continuous and real-time transmission of SHM information.

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