

Analysis of a Decentralized Mobility Management Support for Adaptive Structural Health Monitoring of SOC Public Infrastructures

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Abstract

Recently, structural health monitoring (SHM) for social-overhead capital (SOC) public infrastructures has become a significant factor to prevent the occurrences of untoward accidents or events to ensure public safety. SHM has evolved to the utilization of wireless sensor networks (WSNs) as the core on realizing the real-time and continuous monitoring of such infrastructures. This paper deals with the decentralized mobility management support for an adaptive SHM system intended for SOC public infrastructures in order to prevent disastrous events and accidents caused by natural calamities and disasters as well as to minimize traffic build-up and untoward accidents. The optimization of distributed mobility management (DMM) solutions to provide a robust dataflow of structural and environmental information can be essential in delivering immediate and critical information for an adaptive SHM system to guarantee public safety.

Keyword : Structural health monitoring (SHM), Distributed mobility management (DMM), Social-overhead capital (SOC), context awareness

1. Introduction

The occurrences of natural disasters such as heavy rains, extreme heat, earthquakes, and typhoons have caused severe damages to SOC public infrastructures since the past. Such infrastructure damages have incurred significant amount of property losses as well as to human lives. In this regard, there is an increasing demand for a robust and efficient structural monitoring and maintenance for SOC public infrastructures since these kind of situations keep on happening. SHM system is necessarily becoming a significant approach to foresee the occurrences of natural calamities and thus preventing the untoward accidents and infrastructure failures[1].

Numerous efforts and measures have been implemented to minimize and prevent such disaster damages wherein new challenges and research opportunities arises. One of the interesting challenge is

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with the optimization of the wireless sensor network infrastructure deployed for a real-time and continuous structural health monitoring (SHM) system. In the past, wired sensors have been geographically and permanently deployed on an SOC public infrastructure to monitor the structural health and occurrence of unwanted events. This approach has provided an efficient and continuous structural health monitoring, however, scalability issues have limited its flow distribution as the amount of structural health information also have greatly increased. The utilization of WSN to implement SHM system has addressed these scalability issues and served as an innovative approach to deliver an effective real-time and continuous SHM[2]. The WSN infrastructure can be deployed using a centralized architecture wherein the management and control is relegated into a single central mobility anchor. This anchor will be responsible for the management and control of the geographically deployed sensors and mobile devices within the SHM domain as well as to direct the flow of structural health information[3][4]. The centralized mobility management has been a concrete approach for the SHM system, however, significant number of downsides arises such as scalability, reliability issues (i.e., single point of failure), sub-optimal routing, higher packet loss rate, signaling overhead, lack of granularity on the mobility management service, and leads to a more complex network deployment[3][5].

This paper deals with the analysis of a decentralized mobility management support for SHM system intended for SOC public infrastructures specifically designed for bridges. The approach takes the full advantage of the features of partially distributed mobility management (DMM) solutions to manage the handovers of mobile devices and control the flow of structural and environmental information. The decentralization of the mobility management and control structures is complemented by an adaptive SHM system which is based on context-awareness technologies for data aggregation and signal processing.

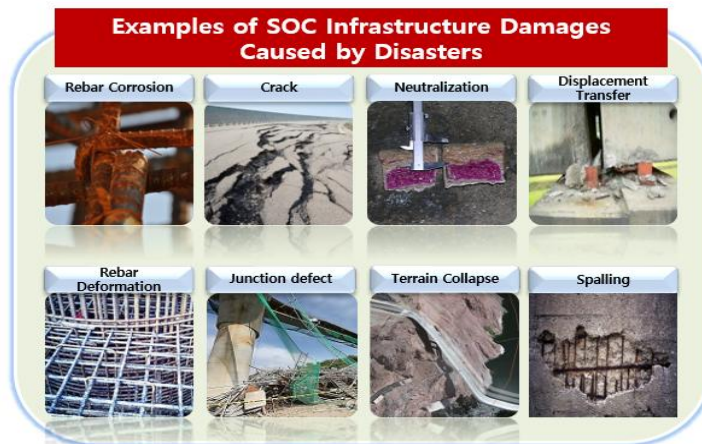
The rest of this paper is organized as follows: Section 2 provides a discussion of the related literature wherein some significant infrastructure damages caused by disasters have been outlined; the overview of the decentralized mobility management support for structural health monitoring is outlined in Section 3; the analysis of decentralized mobility management support for adaptive SHM system based on context-aware technologies is presented in Section 4; and the concluding remarks in Section 5.

2. Related Literature

Over the past years, SOC public infrastructures have been vulnerable for damages caused by natural calamities and untoward accidents such as typhoons, heavy rains, earthquakes, extreme heat, tsunami, landslides, and others. The occurrences of heavy rains, heavy snow, and early morning fog on national

highways, expressways, and on bridges can also cause untoward accidents that could harm the public and provide severe damages to SOC infrastructures. Some examples of SOC infrastructure (e.g., bridges) damages caused by disasters are shown in [Fig 1]. These damages include rebar corrosion, pavement cracks, neutralization, displacement transfer, rebar deformation, junction defects, terrain collapse, spalling, scours, and many more. Water penetration and earthquakes are the most common causes of such damages. These damages to SOC public infrastructures such as railroads, dams, tunnels, national highways, bridges, high rise buildings, communication towers, electrical grid, and others may lead to disastrous events if not have been efficiently monitored.

In this paper, the analysis for decentralized mobility management support for SHM system is specifically intended for bridges as part of the SOC public infrastructures. As bridges are very critical in every country's economy, its failures and collapses can be a significant blow wherein severe damages to properties and even casualties or injuries may occur. Bridge failures can be caused by various factors such as age and deterioration, continuous and heavy rains that leads to flooding, strong winds, construction incidents, earthquakes, fires, design flaws and manufacturing errors, structural issues, and others.



[Fig. 1] SOC Infrastructure Damages Caused by Natural Disasters

The following are some of the bridge failure incidents which have served as the basis for the reevaluation of the safety measures leading to the deployment of robust SHM systems. The Tacoma Narrows Bridge which was opened to traffic in July 1, 1940 has dramatically collapsed on November 7 of the same year. It was observed during construction of its deck that it began to move vertically in windy conditions. Its main span has finally collapsed caused by a 40 miles per hour winds in the

morning the day it has collapsed. The incident has influenced the designs for later long-span bridges[6]. On April 5, 1987, the Schoharie Creek Bridge in New York State in the US has collapsed due to extensive bridge scour at the foundations caused by heavy rainfall killing 10 people. The bridge failure has motivated bridge design improvements and stricter bridge inspection procedures[7]. The I-35W Mississippi River Bridge Minneapolis, Minnesota, US had a catastrophic failure on August 1, 2007 during the evening rush killing 13 people and injured more than a hundred. It was cited that the failure was caused by a design flaw wherein a below standard gusset plate was ripped along a line of rivets which goes along with additional weight that the bridge carries at that time[8].

The Seongsu Bridge in Seoul, South Korea has collapsed early in the morning of October 21, 1994 when one of its concrete slabs fell caused by a suspension structure failure killing 32 people and injured 17 others. It is said that an improper welding on the steel trusses of the suspension structure under the concrete slab roadway may have caused the structural failure[9].

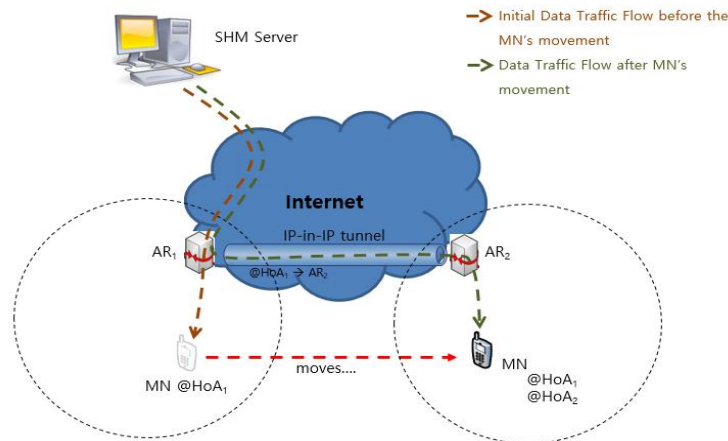
The causes of bridge failures and collapses were mostly attributed to design and construction errors, age and deterioration, and damages caused by vehicular accidents and natural disasters. These bridge failures and collapses have motivated initiatives on bridge construction redesigns as well as stronger and stricter infrastructure inspection policies. To further minimize and prevent such disastrous incidents, structural monitoring systems were implemented to alleviate the standards of bridges and guarantee public safety.

3. Decentralized Mobility Management Overview

SHM system network infrastructure are deployed making mobile systems closer to the mobile terminals in order to meet the emerging exponential growth of structural and environmental information resulting into an increased efficiency. In the SHM system, the mobility management enables the provision of continuous network connectivity to mobile devices and sensors roaming within the SHM domain. It enables different subdomains to interoperate with one another to guarantee seamless mobility and global portability of SHM services for it is essentially important in providing public safety in SOC public infrastructures.

This section provides an overview of the decentralized mobility management as the architectural paradigm solution for evolving SHM systems. Decentralization (also known as distributed) refers to the distribution of control and management among the multiple installed management systems instead of utilizing a single centralized mobility anchor. Each management system referred to as domain managers

will be responsible for independently controlling and monitoring a particular geographical section or domain[10]. The distributed mobility management (DMM) has been worked out by the Internet Engineering Task Force (IETF) for standardization wherein it employs mobility anchors at the edge of the access networks closer to the mobile terminals[11][12]. Its main objective is to optimize the distribution and routing of network traffic (i.e., SHM information) as the mobility anchors are relocated at the edge making it closer to mobile user terminals.



[Fig. 2] The Decentralized Mobility Management Architecture for SHM Systems

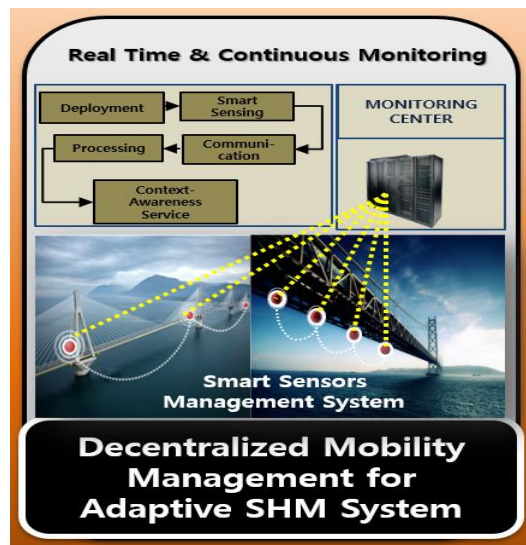
In this paper, the partially distributed model of the DMM framework has been utilized wherein the data (infrastructure) planes were separated from the control plane. That is, data plane is distributed among the network entities creating a balanced network traffic flow. The control plane is managed by a central mobility anchor that provides support for the handovers of mobile devices as well as directing the network traffic flow. The decentralized mobility management support for SHM systems intended for SOC public infrastructures is depicted in [Fig. 2].

4. Decentralized Mobility Management for Adaptive SHM System

This paper deals with the analysis of a decentralized mobility management support for SHM system intended for SOC public infrastructures specifically designed for bridges. The system aims to integrate the decentralized mobility management architecture as an approach for implementing the SHM wireless network infrastructure in order to optimize the flow distribution of structural and environmental information. It aims to fully take advantage of the features of DMM paradigm wherein the mobility

management and control is relegated to a central anchor as well as directing the flow of structural and environmental information. The infrastructure layer (i.e., network entities) will be responsible for a balance distribution of the structural and environmental information within the SHM domain.

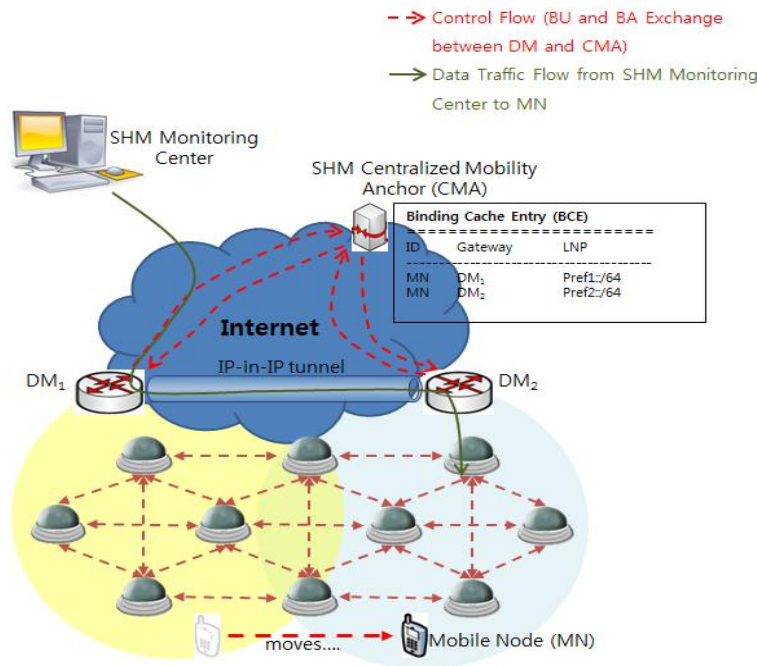
As depicted in [Fig. 3], the SHM system designed specifically for bridges is comprised of the installation of geographically distributed smart sensors capable of measuring bridge health data, occurrences of untoward incidents, and collecting information for weather disturbances such as early morning fog, earthquakes, heavy rainfall, extreme heat, and other natural calamities that can cause damages as described in Section 2 which may trigger any bridge failure or traffic accidents. That is, the adaptive SHM system includes deployment of smart sensors, smart sensing of structural and environmental information, transmission of SHM signals, and processing through context-aware technologies. Smart sensors enable a genetic filtering algorithm wherein only relevant and critical signals will be transmitted into the domain managers. The measured structural and environmental signals will be aggregated, analyzed, and irrelevant signals will be discarded minimizing the transmitted network traffic. This genetic filtering algorithm can be based on a band-pass filter wherein some unwanted components were removed from the signal. For example, rainfall volume, visibility signals, wind strength, and heat signals measured below critical levels will be neglected or discarded by the system and will not be transmitted anymore.



[Fig. 3] Adaptive SHM System based on Context-Aware Technologies

The output of the genetic filtering algorithm will be essential to a faster transmission and processing

of structural and environmental information which will be critical in decision making for an adaptive SHM system based on context-aware technologies. The context-awareness will be utilized to provide an innate decision making capabilities in times when critical structural or environmental information have been processed. Context-awareness enable the SHM system to react and adapt accordingly based on the gathered environmental information at any given time. This process makes the response time automatic resulting into minimized damages for bridges, thus, preventing untoward accidents and disastrous events to happen.



[Fig. 4] Decentralized Mobility Management for Adaptive SHM System

The mobility of the mobile devices such as smartphones or navigators used in vehicles will be managed by domain managers which are responsible for specific regions in a bridge as depicted in [Fig. 3]. Domain managers are also responsible in forwarding critical information (i.e., product of filtering algorithm) into the monitoring center for further processing based on context aware technologies. The SHM system infrastructure is implemented using a decentralized approach optimizing the features of partially distributed model of DMM framework in such a way that the infrastructure layer is separated from its control layer as depicted in [Fig. 4]. The mobile devices (i.e., in vehicles) are capable of receiving a continuous and real-time traffic conditions as well as weather updates as monitored by the

adaptive SHM system. The incoming vehicles register its connectivity to the nearest domain manager (DM) and it is handled in the control layer by the centralized mobility anchor (CMA). Its registration is automatically transferred into the next domain manager as the car moves as CMA is handling its handovers. In such scenario, a seamless connectivity is provided to mobile devices in vehicles providing the drivers with a real-time update of unusual events such as vehicular accidents, heavy traffics, road rerouting, or any occurrences of naturally caused weather disturbances such as heavy rains, heavy snow, foggy of hazy visibilities, strong winds, and others.

As illustrated in [Fig. 4], the SHM Centralized Mobility Anchor (CMA) acts as the centralized controller that manages the mobility of mobile devices (i.e., in vehicles) and directs the flow of SHM network traffic among the infrastructure layer (i.e., domain managers). The optimized route for the SHM information can be determined through checking the bandwidth of every path by checking flag bits during the exchange of binding updates (BUs) and binding acknowledgements (BAs) between the domain managers and the CMA. The optimized route can be double checked through the round trip time (RTTs) of the exchange of these messages. This has allowed for a well-balanced distribution of SHM information providing an efficient and optimal mobility management.

5. Conclusion

This paper has presented an analysis of a decentralized mobility management support for an adaptive SHM system based on context-aware technologies intended for SOC public infrastructures specifically designed on bridges. It takes full advantage of the features of partially distributed model of DMM framework in optimizing the handovers of mobile devices (e.g., smartphones or navigators used by vehicle drivers) and balancing the flow distribution of SHM information traffic such as environmental or weather disturbances, occurrence of untoward incidents, and structural health information. The analyzed system was designed to prevent the occurrence of untoward accidents preserving human lives for unexpected disasters or calamities that might happen. In addition, the system employs a genetic filtering algorithm to limit the transmitted signals and processing only the critical information and discarding the irrelevant measured signals. Context-aware technologies have been utilized to provide an adaptive decision making capabilities based on the measured structural and environmental information to ensure the provision of a real-time and continuous SHM system, and thus, guarantee public safety on bridges.

References

- [1] J. P. Lynch, "An overview of wireless structural health monitoring for civil structures", *Philosophical Transactions of the Royal Society*, vol. 365, (2007), pp. 345-372, doi:10.1098/rsta.2006.1932, Published online: 14 December 2006.
- [2] S. J. Cho, C. -B. Yun, J. P. Lynch, A. T. Zimmerman, B. F. Spencer Jr., and T. Nagayama, "Smart Wireless Sensor Technology for Structural Health Monitoring of Civil Structures", *Steel Structures*, vol. 8, (2008), pp. 267-275.
- [3] P. Bertin, S. Bonjour, and J. Bonnin, "Distributed or centralized mobility", In *Proceedings of IEEE Global Telecommunications Conference (GLOBECOM 2009)*, IEEE, (2009), pp. 1-6.
- [4] <https://2wtech.com/centralized-mobility-management/>, Retrieved: (2019) March 20.
- [5] Y. Wang, J. P. Lynch, and K. H. Law, "Wireless Sensing, Actuation and Control - With Applications to Civil Structures", In: Smith I.F.C. (eds) *Intelligent Computing in Engineering and Architecture, EG-ICE 2006*, Lecture Notes in Computer Science, vol. 4200, (2006), Springer, Berlin, Heidelberg, https://doi.org/10.1007/11888598_60.
- [6] Washington State Department of Transportation, "Tacoma Narrows Bridge", <https://www.wsdot.wa.gov/tbnhistory/connections/connections3.htm>, Retrieved: April 10, 2019.
- [7] <https://www.timesunion.com/local/article/30-years-ago-Bridge-collapse-kills-10-11045976.php>, Retrieved: April 10, 2019.
- [8] NTSB, "Collapse of I-35W Highway Bridge, Minneapolis, Minnesota, August 1, 2007", National Transportation Safety Board, <https://www.nts.gov/investigations/AccidentReports/Reports/HAR0803.pdf>, Retrieved: April 10, 2019.
- [9] Reuters, "32 Reported Dead as Bridge Collapses in Seoul", 1994, October 22, <https://www.nytimes.com/1994/10/22/world/32-reported-dead-as-bridge-collapses-in-seoul.html>, Retrieved: April 10, 2019.
- [10] H. A. Chan, H. Yokota, J. Xie, P. Seite, D. Liu, "Distributed and Dynamic mobility Management in Mobile Internet: Current Approaches and Issues", *Journal of Communications*, Academy Publisher, vol. 6, Issue 1, (2011), pp. 4-15.
- [11] J. C. Zúñiga, et al., "Distributed Mobility Management: A Standards Landscape", *IEEE Communications Magazine*, vol. 51, no. 3, (2013) March, pp. 80 - 7.
- [12] B. Sarikaya, "Distributed Mobile IPv6", IETF Internet-Draft, (2012) February.

