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Architectural Frameworks for Integrated Communication Systems related to Traffic Management in Smart Cities

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Abstract: One of the major goals of developing countries is to build smart cities to avoid various types of congestions, accidents and many kinds of inordinate delays through advanced and intelligent traffic management systems. An intelligent traffic management system can be conceived through many of individual sub-systems which include bio-sensing system, imaging system, messaging system, cognitive system and visualization, remote sensing and communication systems. Each of the sub-systems while is expected to work independently, they should also be in existence in unison along with other sub-systems. In a traffic management system, communication between heterogeneous systems which are situated either in local or remote locations have to be undertaken. Series of transformations are needed to move information from one location to other. Different kinds of communication protocols are to be used for effective communication and yet, times require protocol conversions. Both local and remote communication has to be undertaken in an intermixed manner. It also becomes necessary to inter-mix Wi-Fi, optical, cellular methods of effecting communication. This study presents a hybrid architecture that meets all types of communicating requirements to implement an intelligent traffic system.

Key words: Architectural frameworks, traffic management systems, hybrid communication systems, requirements, intermixed, remote

INTRODUCTION

Mobility is ever increasing in the industrialized world while road capacity is reaching its limits. It has become necessary to find the new uses of existing technologies or find organisational structures that help reducing the need for travelling or to use the existing infrastructural facilities more effectively. Communication systems are expected to play a major role in the implementation of the selected solutions. The continuous increase in the congestion level on public roads, especially at rush hours is a critical problem in many countries and is becoming a major concern to transportation specialists and decision makers. The existing methods for traffic management, surveillance and control are not adequately efficient in terms of the performance, cost and the effort needed for maintenance and support.

Technological advances are in verge and more of them are required for informing the traffic conditions to motorists, make the commuters reach their destinations in shorter times, avoid congestions, increase reliability of the travel, increase the safety and decrease the accident response time and traffic avoidance in rural and urban area. Many advanced traffic management systems are being invented to address these issues and as such they have become a necessity and not a luxury due to ever increasing road traffic, intelligent cars on anvil and every body's life is running on minutes if not in seconds.

In particular, Traffic Management Systems (TMS) is the integrated application of advanced information processing and communications, sensing, display and control technologies to surface transportation, both in the vehicle and on the highway. TMS technologies involving sensing and communication could automatically warn a driver of impending danger. The technologies may also assume some of the control functions that are now totally the responsibility of drivers, compensating for some of their limitations and enabling them to operate their vehicles closer together but more safely.

Smart cities is a significant paradigm shift of interest towards proposing and using various innovative and new technologies to make cities "smarter" in order to improve the people's quality of life. Traffic is considered as a very important and highly visible initiative in smart cities. Strictly related to transportation, the goal is to identify and support sustainable forms of transportation and to build intelligent public transportation systems based on real-time information and the need for congestion avoidance, improve safety and to create green environment.

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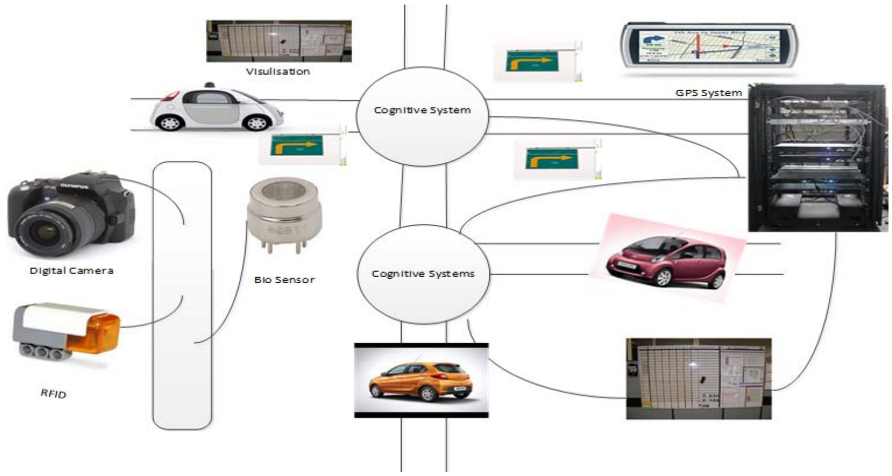

Fig. 1: An aerial overview of a typical traffic management system

There has been tremendous growth in the usage of cars using the limited road infrastructure. Traffic congestion is leading to delay in emergency services due to the inability in moving police, fire engines, rescue teams, ambulance, medical services, etc. Additionally, latest road traffic statistical information reveal that there the is increase in the number of vehicle crashes due to traffic congestions. Many of the large cities in the world are still suffering from traffic congestion, in spite of employing different kinds solutions to reduce it, including use of traffic management systems that deploy advanced congestion control mechanisms.

Unfortunately, to date, the existing TMSs do not provide sufficient and accurate road traffic information to enable granular and timely monitoring and management of the road traffic network. Some of the reasons include lack of granular data collection, inability to meaningfully aggregate much of the data collected and a lack of complex management systems capable of providing accurate views of the road transport network. An aerial view of a typical modern traffic system is shown in Fig. 1.

Literature review: Several studies have been made earlier and different traffic management systems have been implemented that include ATMS (Automatic Traffic Management System), Knowledge Based System (KBS), Intelligent Traffic Management System (ITMS), Traffic Congestion Management (TCM), etc.

Logi and Ritchie (2001) described a real-time Knowledge Based System (KBS) for decision support in the selection of integrated traffic control plans after the occurrence of non-recurring congestion. Zhenlin *et al*. studied the efficiency of the Beijing Intelligent Traffic Management System (ITMS). In this study, urban transportation systems, socio-economic system and energy environment system were taken as the input system and the road traffic management efficiency and urban transport putting indicators as the output system. Hernandez *et al*. (2002) incorporated the use of artificial intelligence. Mulay *et al*. (2013) gave the traffic management system which provides facility of congestion detection and management, ATMS developed by Balaji and Srinivasan (2011) provides only the traffic signal control for the management of traffic. Logi and Ritchie (2001) used Traffic Congestion Management (TCM) approach which estimates current traffic conditions using the result of a static assignment based on historical O-D data that represent daily traffic pattern under different conditions.

System developed by Ossowski *et al*. (2005) have been capable of handling different traffic incidents through different methods but was unable to handle any traffic incidents. Djahel *et al*. (2015) proposed communication architecture for traffic management. In the TMS, they have proposed the traffic management to be done in four different phases which includes Data Sensing and Gathering (DSG), Data Fusion, Processing and Aggregation (DFPA), Data Exploitation (DE) and Service Delivery (SD).

A key technology that is a promising solution for reliable and fast traffic data monitoring and collection is the Machine 2 Machine (M2M) communication.In M2M communication (Lucero, 2010), a sensor gathers traffic data and sends them via. wireless communication/cellular/ 3G/LTE networks toward one or multiple central servers for processing purposes. The ability of M2M devices to avoid the multi-hop transmission as opposed to WSNs, makes the data transmission faster and more reliable, which represents a significant benefit for the sensors reporting delay critical events. Moreover, it is foreseeable that this technology will significantly enhance the accuracy of data collection and lead to more flexible deployment of sensors on the roads.

Hussian *et al*. (2013) proposed an automated intelligent traffic control system. In this system they have used ZigBee wireless technology for communication. ZigBee is a specification for a suite of high level communication protocols using small, low power digital radio for personal area networks. ZigBee devices are often used in mesh network from to transmit data over longer distances, passing data through intermediate devices to reach more distant ones. This allows ZigBee networks to be formed adhoc with no centralized control or high power transmitter/receiver able to reach all of the devices.

There are three types of ZigBee devices used as on date which include ZigBee Coordination (ZC), ZigBee Router (ZR), ZigBee End Device (ZED).The Protocols build on recent algorithmic research to automatically construct a low speed AD-HOC network of nodes. In most large network instances, the network will be a cluster of clusters. It can also form a mesh or a single cluster. The current ZigBee protocols support beacon and non-beacon networks.

Ilarri *et al*. (2015) have chosen vehicle to vehicle communication and adhoc to infrastructure based communication for the communication prospective of traffic management system. Data dissemination is done in such a way that a data dissemination protocol is needed to enable the exchange of information among vehicles. Several strategies can be applied to guarantee an effective and cost-efficient data dissemination. Usually, these strategies are adapted to the specific case of vehicular networks which are highly dynamic as approaches for general MANETs are usually considered in appropriate for VANETs (Schwartz *et al*., 2011).

Bento *et al*. (2012) proposed their intelligent traffic management at intersections supported by V2V and V2I communications. ITMS require a secure channel for information exchange between vehicles and infrastructure. The current Communication System (CS) technology, namely wireless, already provides reliability in communications. In the ISR-TFS, a communication system is simulated with two operation modes: simulated-Fast and simulated-Real. In the simulated-Fast mode the CS delivers messages instantly and the only constraint taken into account is to verify whether each agent is within, or not, in the range of other agent's antennas. Based on the research of Ray *et al*. (2005) they have developed a two-dimensional wireless network discrete event simulator, to approximate the simulated CS to a real CS system.

Bento *et al*. (2013) had also proposed intelligent traffic management at intersections legacy mode for vehicles not equipped with V2V and V2I communications. In this he described a legacy algorithm for an intelligent traffic management system applied to automatic regulation of traffic at intersections. The application of the legacy algorithm enables the intelligent intersection to accommodate vehicles, in a low percentage, not equipped or with faulty V2V and V2I communications (Bento *et al*., 2012). Using the vehicle's position, the intersection management system computes the distance from the vehicle to the intersection. When the vehicle enters in a predetermined control radius, the infrastructure agent runs the selected ITM algorithm. For each vehicle request, the selected ITM algorithm generates a collision-free path to be followed by the vehicle while traversing the intersection.

MATERIALS AND METHODS

This inability to effectively monitor and manage the traffic keeps traffic congestion high, which, in turn, affects road safety, augments fuel consumption and causes large gas emissions. The main solutions used by the existing TMSs to manage the traffic after an incident or during peak hours are changing/adapting traffic light cycles, closing road lanes and intersections, etc.These solutions have limited efficiency when the increasing numbers of cars are using the limited road infrastructure and constantly, new solutions to be used by TMSs are being proposed by the research community.

In a traffic management systems, different types of communication systems are to be used for establishing communication either locally with signal post systems or with base stations that are situated at a distance or with remotely situated traffic monitoring and controlling systems.

The local communication may be fully based on networking embedded systems or through use of communication systems such as Wi-Fi or Bluetooth, etc. The communication with base stations may take place either through cellular or microwave based communication and the communication with a remote sever may needs to be done using either microwave or satellite based communication. The end-to-end communication starting from a sensor to the remote server system requires use of many types of communication systems which can be termed as hybrid communication. Hybrid is defined as something that is a combination of two or more different things. A hybrid communications system might support both digital and analogue signals or perhaps both circuit switching and packet switching.

In hybrid communication system as said above the data communication can be done by using the both digital and analogue signals. The communication can be done either by using wired or wireless channels. Many embedded networking related communication systems which include Controller Area Network (CAN bus), Local Area Network (LAN), RS485, fire wire, Universal Serial Bus (USB), fire wire can be used. Wireless technologies primarily the Wi-Fi, ZigBee can also be used for effecting communication in local areas. IR (Infra-Red) can be used when perfect line of sight exists. Cellular communication can be used when the frequency required is in 1.0 Giga Hertz (GHz) to 30 GHz spectrum. Microwave communication can be used when point-to-point communication is required due to the requirement of their small wavelength that allows conveniently-sized antennas to direct them in narrow beams which can be pointed directly at the receiving antenna. Satellite based communication can be used especially when the communication has to be carried over long distances.

In a typical traffic management system many devices are used for monitoring and controlling the flow of traffic. The devices collects, stores and processes different types of data which include video, audio, Image, spatial, temporal. The devices are heterogeneous in nature as they are built using different types of technologies and are provided with different types of communication interfaces such as Bluetooth, WI-Fi, etc. Sometimes no communication interface as such is supported within devices like cameras, display systems, sign systems, etc.

Small devices are expected to communicate locally in peer to peer communication mode using several alternate communication routes. The small devices also have to communicate with distantly located local base stations or remotely situated central traffic monitoring and control system. At times, small devices have to communicate using heterogeneous protocols. Some of the small devices which are meant for dealing with specific parameters need to be connected in bus kind of topology each communicating with other devices using serial communication protocols such as CAN, I^2C, USB, RS485, etc.

Thus a typical traffic management system requires use of several kinds of communication systems which either operates locally or remotely using heterogeneous protocol or interface systems. Thus it becomes necessary to develop a communication system using heterogeneous interfaces, protocols, topologies requiring interconnecting of different types of networks or undertaking protocol conversions. A composite type of communication system which is hybrid in nature is necessary for implementing integrated traffic monitoring and controlling system.

The communication system must be highly reliable and real time. Information processing must be undertaken as fast as possible. The data transmission systems used for effecting communication must take into account all issues related to data rates and the speeds at which communication must be effected. The data transmissions overheads must be reduced to as much small data size as possible.

The communication system will involve using different systems which include use of protocols such as CAN, I^2C, USB, RS485, etc., bridging different types of networks that include cellular, satellite, micro wave, wireless and wired communication systems and implementation of protocol conversion, interface conversion systems.

The communication system meant for a traffic management system should be built considering the issues such as heterogeneity of networking nodes, bridging networks, protocol conversion, use of different types of topologies, interface conversions, using alternate paths for communication, supporting both local and remote communication. Considering all these issues, building a universal communication system is quite complex and needs to be addressed as one of the most critical aspect of implementing a traffic management system.

RESULTS AND DISCUSSION

In a typical traffic management system, communication system plays most critical role. Many types of communication system have to be supported for effecting communication between different kinds of sensors, local base stations and remote sensing systems and remotely situated central server. The communication must be effective and fail safe. The response from the communication system must be very high in the order of more than 3 sec. Due considerations must be given to communication lengths, protocols and proper functioning of the communication devices. The type of communication system that must be used is very much dependent primarily on the distance to which the transmitting and receiving systems are located. The following study explains the architectural designs of such systems.

Architectural frameworks for communication between local hosts and central server: Communication between a local host and the central server is most critical to the traffic communication system. In atypical communication setup four local hosts and a centralized server have been considered. The hosts and the centralized server are separated by long distance from each other, so, the communication chosen between them is satellite communication as shown in Fig. 2.

The hosts are separated from each other at short distance compared to centralized server, therefore the communication medium chosen between them is satellite communication or cellular communication or microwave communication. All the local hosts and the centralized server are interconnected with each other. If there is data to be sent from a local host to centralized server, the same can be affected through satellite communication. If there is a problem in the satellite leaking then the data could be routed through another base station that could effectively communicate using its own satellite link. Similarly, if the data is to be sent from centralized server to a local host and if the satellite link fails then the data is routed through the satellite link that is functioning with another base station.

Architectural framework for establishing communication between signal post and local base station: The communication system that can be effectively used between the signal post system and local base station is shown in Fig. 3 in which communication system that caters for four traffic posts and one local host has been presented. The traffic post system deals with different devices such as video cameras, digital cameras, cellular communication and bio sensors which senses and captures the ongoing data from time to time. The data is sent to central server through local hosts for processing. The processed data is sent in return from the central server to local host from which the data required for actuating various systems is sent. The signal posts are separated from each other at a short distance so they can be communicated with each other using wired or cellular communication. The distance between local host and the signal post is very long, so, the communication chosen could be either cellular, microwave or satellite. If the path to transmit data from one signal post to local host

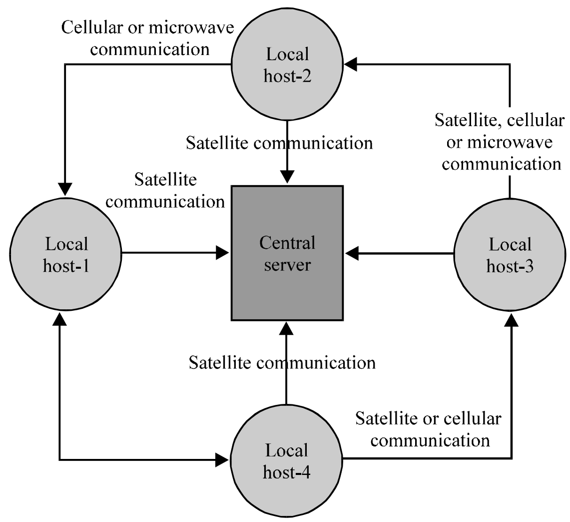

Fig. 2: Communication between local host and serevr

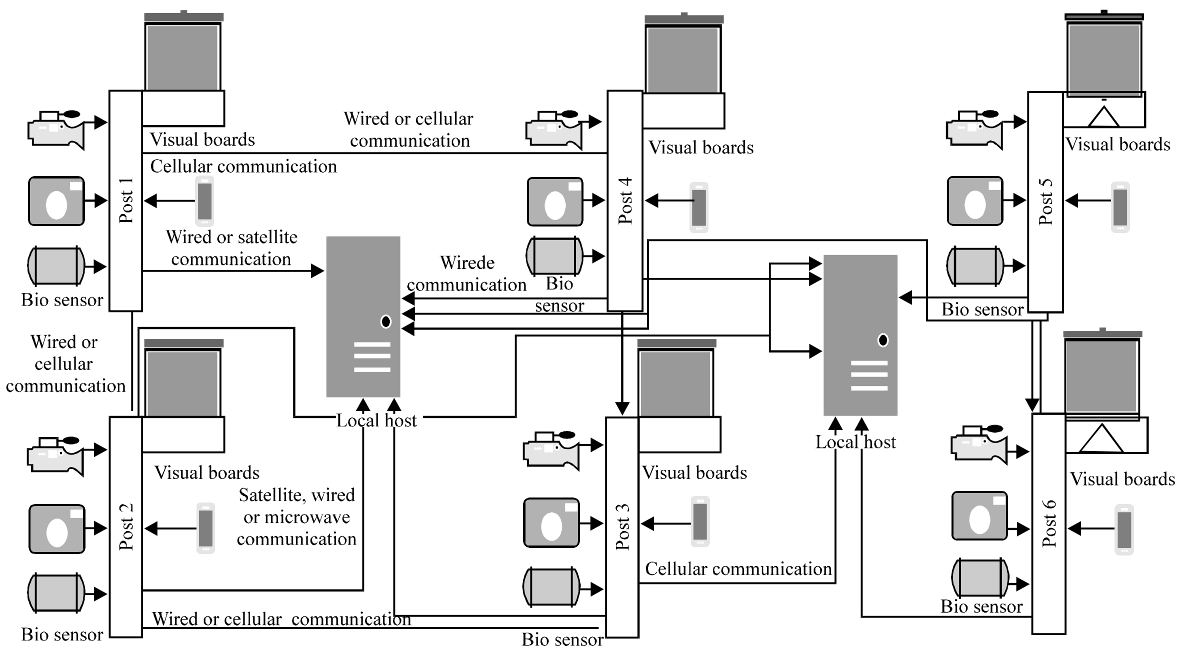

Fig. 3: Establishing communication between signal post and local base station

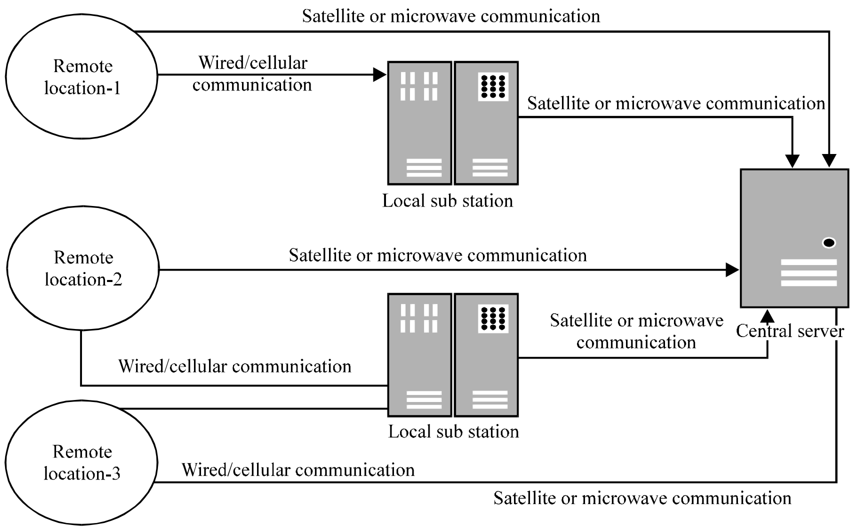

Fig. 4: Communications between remote location and remotely situated central server

through one of the means (cellular, micro wave or satellite) is non-existent, an alternative path through adjacent signal post is selected for transmission of the data. Thus the existence of many alternative paths of communication between a signal post and local base station exists leading to completely fail safe and reliable communication system. The communication redundancy induced into the system is highly reliable. Special care is taken totransmit information gathered from heterogeneous peripherals situated in remote regions. They are connected to both local host and central server directly.

Architectural framework for establishing communication between a remote location and a remotely situated central server: Any accidents or incidents when happens needs to be informed quickly to either a local base station or to a remotely situated computing system so that corrective actions are quickly taken either to decide alternate routes of commuting or to initiate rescue operations. Communication with base station must be effected through either Wi-Fi or cellular or through microwave/satellite if the central computing server is at far end locations which could not be reached by any of the communication system. The connectivity of an object at a remote location and with local base station or remotely situated computing server is shown in Fig. 4.

If any accident takes place at a remote location, the information must be sent to the central server to take necessary controlling actions. The information related to the accident can be transmitted to the local host by using either wired or cellular communication and through satellite or microwave communication to the central server. If the distance between the remote location and local host is short compared to the distance between remote location and central server, the message is sent to the nearby local host and then transmitted to the central server. The information is passed through shortest route possible, i.e., if the distance between the remote location and the central server is short compared to the distance between remote location and local host, the message is transmitted to central server directly using satellite communication.

Comparative analysis of communication architectures: The survey of literature revealed that no work has been done that presents architecture frameworks that explain composite communication system for traffic management system. Some architecturehas been presented that deal with communication in a limited manner (Anonymous, 2003). Comperison of the architectures presented by many has been shown in Table 1. From the comparisons it can be seen that most of the communication is achieved through RS232C which is not quite suitable for communicating either with local base station or remote control station due to distance limitations. As such no alternative paths of communication have been included into the architecture which is required for communicating with either local or remote computing stations for effective traffic management systems. From Table 1, it can be seen that the proposed architectural framework is versatile, ruggedized and fail safe as many alternate paths of communication could be supported.

Table 1: Comparisons of architectural frameworks

	Proposed model					GES and other Models				
Communication link	Wi-Fi	Cellular	Microwave	Satellite	Wired	Wi-Fi	Cellular	Microwave	Satellite	Wired
From device to signal post (direct)	√	√	×	×	×	×	×	×	×	√
From device to signal post (in direct)	√	√	×	×	×	×	×	×	×	×
From signal post to local host (direct)	×	×	√	√	√	×	×	×	√	√
From signal post to local host (in direct)	×	×	√	√	√	×	×	×	×	×
From device to local host (direct)	√	√	×	×	√	√	×	×	×	√
From device to local host (direct)	√	√	×	×	√	√	×	×	×	√
From local host to remote host (direct)	×	×	√	√	√	×	×	×	√	√
From local host to remote	×	×	√	√	√	×	×	×	×	×

CONCLUSION

A modern traffic management system involves the use of several electronic systems which are to communicate with each other seamlessly. The communication must be ruggedized and fail safe as 24×7 operations are expected. The electronic systems to be used for monitoring and controlling the traffic are heterogeneous in nature and therefore the communication system must be built with protocol conversions, bridges and converters, etc. A framework is needed for establishing a communication system that takes into account all the complexities involved in making traffic management system quite effective. The framework presented in this report caters for all the complexities involved in establishing communication between all the gadgets that are used for managing the traffic.

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