WSN Architectures for Intelligent Transportation Systems

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***Abstract*—The emergence of, and advancement in, integrated digital circuitry technology along with the development of efficient software algorithms made it possible to build small, lightweight wireless nodes equipped with embedded processors, sensors and radio transceivers. By densely deploying these nodes, in a highly distributed manner, we can build a Wireless Sensor Network (WSN). In this network, sensors collaborate in monitoring physical parameters or environmental conditions, such as temperature, sound, vibration, etc. Sensor nodes frequently report the data they capture to a central collection unit that analyses the data and takes appropriate actions if needed. Intelligent Transportation Systems (ITSs) emerged as a potential candidate for benefiting from the unique features and capabilities of WSNs. In ITSs, transportation infrastructure is supported with the ingenious achievements of computer and information technology to resolve severe situations like traffic congestion and cope with emergency conditions like major accidents. In this paper, we study the requirements for an efficient WSN architecture for ITSs, survey the WSN architectures proposed for this type of applications highlighting their strengths and weaknesses, and shed light on future directions in this field of research.**

***Index Terms*— Wireless Sensor Networks, Intelligent Transportation Systems, Network Architectures.**

I. Introduction

THE significant advances in hardware manufacturing technology and the advent of the Micro-Electro-Mechanical-Switches (MEMS) paved the way for building smart sensor nodes that are capable of performing three important functions: sensing, processing, and wireless communication. These wireless sensor nodes are characterized by being intelligent, small-sized, low in cost, battery-driven, and easy to install and repair. These characteristics opened wide doors for a broad range of applications attained by deploying wireless sensor nodes in a dense, distributed manner to form specialized Wireless Sensor Networks (WSNs). The main objective of WSNs is to monitor physical or environmental phenomena like temperature, sound, vibration, relative humidity, pollutants, etc. They also collect data to be reported to a central processing unit that analyses the gathered data and take certain measures accordingly. Starting with critical military applications like battlefield surveillance, WSNs eventually entered enormous number of civil applications such as motion tracking, traffic monitoring, fire detection, seismic sensing, home automation, to mention only few. The different aspects of WSNs attracted extensive research activities and a large body of studies is now available [1] [2].

An interesting field where the use of WSNs proves effectiveness is the field of Intelligent Transportation Systems. An Intelligent Transportation System uses technological advances in computers and information technology to improve the efficiency of both new and existing transportation systems [3]. By providing surveillance and tracking services, traffic conditions, in both urban and rural areas, can be monitored continuously. A direct consequence of that is resolving the congestion problem by properly directing the traffic away from the highly crowded and congested roads. Moreover, ITSs can be used to manage parking lots, report emergency situations, navigate destinations, propagate traffic conditions on highways, provide traveler information, avoid vehicle collisions, and enhance driver's safety. Various governmentally-funded ITS projects have been launched in many countries like Canada [4], USA [5], Europe [6], Japan [7], Australia [8], and others. Furthermore, various projects have been funded by educational institutions, regional organizations, and the industry to research ITS. Examples include CAPTIV [9], SAFESPOT [10][11], PATH [12], FLEETNET [13][14][15], CVIS [16], TRACKSS [17], and MORYNE [18]. The growing interest in ITSs drove the development of many frameworks (like ART-Wise [19]) and standards (like WAVE (IEEE 802.11p) [20, 21] and CALM [22, 23]). ITSs depended on traditional monitoring sensors including inductive loops, video cameras, ultrasonic sensors, radar [22]. However, these sensors suffered from major drawbacks that affected the sole purpose behind incorporating intelligence in transportation systems. In particular, these sensors are bulky, power-hungry, expensive to install, maintain and repair, and connected through wires to central data processing locations. These characteristics subvert the scalability of ITSs and affect their major objectives, like traffic monitoring or collision avoidance. Incorporating WSNs into ITSs can be enticing due to their special features that

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overcome the problems associated with traditional wired sensors. Wireless sensor nodes are small-sized, cheap, simple to install, densely deployed, power-efficient, and can be effectively self-configured to cope with sudden failures in nodes [1]. The fact that a single WSN is constituted by a large number of sensor nodes solved the scalability problem of traditional ITSs. Wireless sensors provide enhanced coverage of the transportation infrastructure and thus better decisions in the management of the traffic can be attained.

The deployment of WSNs in ITSs attracted the research communities and several studies investigated the benefits of that initiative. In [24], Tubaishat et al. categorized the applications of WSNs in ITSs under three major fields: 1) Monitoring parking lots, 2) Traffic monitoring and control, and 3) Traffic estimation. It is important to note that these applications encounter two types of information communications, namely, Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications. In V2V, vehicles are equipped with sensors in order to exchange information that is crucial to avoid severe situations like traffic jam avoidance [25][26][27]. In V2I, information flow from vehicles to sensors installed on roadway infrastructure. This communication is necessary in propagating awareness about traffic conditions, especially on highways, to support safer commuting [26]. An interesting area of research in this context is the Vehicular Ad Hoc Networks (VANETs) where a unique area of wireless communications that utilizes WLAN technologies to support V2V and V2I. However, VANETs are beyond the scope of this paper and more information about them can be found in [28].

There have been extensive proposals in the literature to support V2V and V2I communications that benefit from the characteristics of WSNs. These proposals employ different WSN architectures to serve different objectives and applications. In this paper, we review these architectures and highlight their strengths and weaknesses. The rest of the paper is organized as follows. In Section II, we discuss the key factors that drive the design of Wireless Sensor Networks. Section III provides an overview of WSN architectures. Section IV details the design requirements of WSN architectures for ITSs systems. Section V presents the available WSN architectures proposed in the literature to support ITSs and compares these architectures to draw a conclusion about their strengths and weaknesses. Section VI provides an example of simulations carried out to evaluate the performance of a WSN in an ITS. Finally, Section VII concludes our work and states some future directions in researching WSN architectures for ITSs.

II. Design Requirements of WSN

The architectures of WSNs emerged from the experience gained from devising architectures for self-organizing, mobile, ad hoc networks [29]. The latter show emphasis on the need for decentralized, distributed form of organization and this is a shared characteristic with WSNs. They benefit from the evolutions in real-time computing, peer-to-peer computing, active networks and mobile agents/swarm intelligence. Besides the networking and computing concepts just mentioned, many other factors play a significant role when devising architectures for a WSN. Below, we list the critical factors that distinguished between different WSNs architectures.

Fault tolerance: WSNs are mainly monitoring important phenomena. Therefore, it is essential for a WSN to sustain its functionality without disruptions, even if some nodes malfunction or die. Usually, WSNs are deployed in hostile environments where nodes may be damaged, due to environmental interference, or eventually die due to the impracticality of recharging or replacing their batteries. Nodes in a WSN are prone to failures and this may result in sever situations like partitioning the network. The design of a WSN should guarantee that its functionality and services are never degraded by these failures.

Scalability: Sensor nodes are deployed densely to form a WSN. This huge number of nodes has a direct impact on the design of schemes and protocols at different layers. For example, a MAC protocol (data-link layer) should be able to grant, in a fair fashion, each node access to the medium while minimizing or preventing collisions, which is very difficult given the huge number of available nodes. Also, a routing protocol (network layer) that depends on exchanging routing tables among nodes may not be efficient since there will be excessive control traffic that underutilizes the bandwidth of the medium.

Production cost: The cost of a single sensor node should be minimized since it determines the overall cost of the network under design.

Network topology: The fact that Wireless Sensor Networks are constituted by a huge number of nodes raises the challenge of network topology maintenance and modification. The challenge occurs starting at the early stage of nodes deployment. Sensor nodes can be either thrown in a mass (e.g., from a plane) or manually placed one by one (e.g., by a human or a robot) in the field. Also, after nodes deployment, topology may change due to failures in some nodes, changes in nodes locations, lack of reachability (due to jamming for instance), and huge reductions in power resources at some nodes (which affect their transmission power levels to the limit that they vanish from the vicinity of neighboring nodes). The WSN should be able to adapt to these sudden changes to avoid any degradations in its functionality.

Security: In the environment of deployment, sensor nodes are either deployed very close to the phenomenon of interest or directly inside it. As a result, we can see that WSNs are usually not supervised (especially in remote geographic areas). This means that WSNs may be targeted by intruders to exploit any security vulnerability.

QoS support: Time-sensitive applications (especially in military) require support for real-time communication that provisions guarantees on maximum delay, minimum bandwidth, or other QoS parameters.

Power consumption: this is a primary design factor for any WSN. Power consumption should be made minimal in order to prolong the lifetime of the network. In fact, "power conservation" is a distinguishing factor between designing a WSN and designing other classes of wireless networks. The latter may consider QoS parameters (like, delay, throughput, fairness, etc.) as key design requirements. Based on this observation, research activities target the development of power-aware protocols and algorithms for sensor networks. That is, power-awareness should be incorporated in every stage of designing a WSN. In fact, power-awareness imposes constraints on the size and complexity of a sensor node's platform. In this context, hardware of sensor nodes should be designed to be power-efficient.

III. WSN ARCHITECTURES

With all those facts about WSNs in mind, a vast number of architectures have been proposed for WSNs in the literature (the interested reader is referred to Chapter 3 of [29] where the authors provide a comprehensive list of publications dedicated to explore WSN architectures). In general, nodes of a WSN are scattered in a field. These nodes collaborate in gathering data and disseminating them to a "sink" node. Usually, the sink node is a base station (BS), which is a single powerful station that connects the WSN to a wired network. A BS is usually supported with more power resources and far more communication and processing capabilities than a wireless sensor node. We can identify two basic WSN architectures and most of the other architectures can be derived from or understood based on them:

A. Layered architecture

Sensor nodes in this architecture are arranged in layers around the BS with each layer containing nodes that have the same hop-count to the BS. Nodes that are one-hop away from the BS are included in the first layer; nodes that are two-hops away from the BS are included in the second layer; and so on. The main advantage of this architecture is that nodes in a layer are involved in a short-distance communication with their neighboring layers. This leads to efficient power conservation, which is a key design factor as we will see later. This architecture is illustrated in Figure 1(a).

B. Clustered architecture

Sensor nodes in this architecture, as illustrated in Figure 1(b), are arranged in clusters, each governed by an elected cluster-head. In this architecture, nodes in a cluster exchange packets with their respective cluster-head. Only the cluster-heads communicate with the BS. In each cluster, the cluster-head aggregates the data it receives from the cluster members and eliminates any occurring redundancy. The latter feature significantly reduces the volume of communication traffic received by the BS.

Towards designing WSN architectures for ITSs, we will be governed by all the factors we mentioned in this section

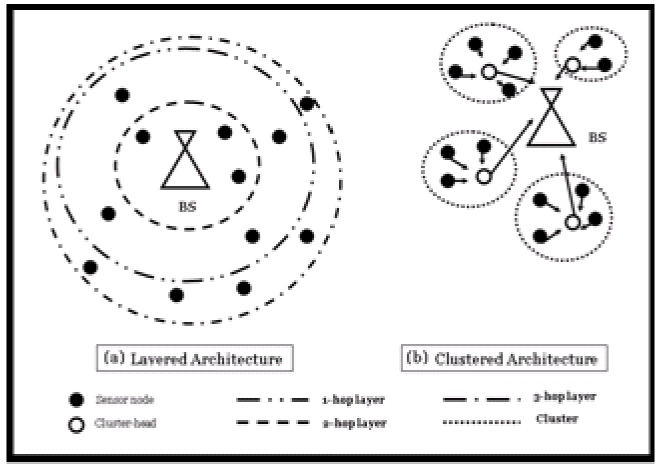

Fig. 1: General depiction of WSN architectures

IV. DESIGN REQUIREMENTS FOR ITSS

There have been extensive contributions towards benefiting from the unique features of WSNs in supporting diverse applications for efficient ITSs [31-39]. In Section II we highlighted the main design requirements for WSN architectures. While these architectural requirements hold for any application, we observe that we have potential opportunities to relax some of those requirements when dealing with Intelligent Transportation Systems:

A. Fault tolerance

An ITS can be deployed in both urban and rural regions. For the urban regions, the ITS is usually safe from instable environmental conditions and thus sensor nodes failures will be minimized. This has its direct impact on prolonging the lifetime of the WSN, maintaining its topology, and designing the different protocols especially routing and MAC protocols.

B. Scalability and production costs

Although WSNs are characterized by deploying a large number of sensor nodes. In fact, an efficient ITS is expected to span hundreds of roads and regions. This draws a major concern about how large the WSN will be in order to cover that huge area. This observation motivated the research in the area of "traffic estimation". With traffic estimation, only a small fraction of the road systems will be measured and monitored by a WSN [24]. The information collected from that small fraction will be used to estimate traffic data at locations where sensors are not deployed. As a result, the size of the WSN, and therefore its deployment costs, will considerably drop. Moreover, traffic estimation supports the scalability of the WSN.

C. Power consumption

In an ITS, sensor nodes are installed on vehicles or on roadsides. The former can use vehicles' batteries to supply sensors with power while the latter can use solar cells for that purpose. As a result, there is no power constraints for WSNs in an ITS. This means that sensors can handle more complex processing and complex computations which allows for using routing protocols with expensive computational requirements. In other words, power conservation is the primary design factor that drives the implementation of MAC and routing protocols. Other QoS factors are usually dealt with as secondary factors. Relaxing the power factor allows designers to focus on implementing routing and MAC protocols that can support more QoS parameters like reduced time delays, higher throughputs, fairness, etc. Therefore, they can support more sophisticated applications. The applications of updating drivers of severe emergency, security, weather, or life-threatening conditions are time-sensitive and can strongly benefit from QoS support in ITSs. The fact that sensors are limited in memory and processing capabilities will still impose an upper limit on the performance sought to be achieved.

D. Network Topology

The fact that sensors are deployed on roadsides, or at known locations, eliminates the burden of implementing node localization algorithms. In fact, monitoring vehicles is among the primary targets of an ITS. By having accurate information about the locations of each node, we can attain accurate information about the events taking place on the roads. Also, given the facts about the stable environment and the availability of power resources, there is a good opportunity of minimizing the possibility of partitioning the topology of the network by minimizing node failures. Therefore, the design of routing protocols will be simplified as the factor of "adapting to the changes in the topology" will not be a major concern.

E. Security

It's another major factor in designing an ITS. Manipulating the data exchanged among sensor nodes in order to reflect a corrupt or fake image about the traffic or conditions on the roads may be a major target for intruders and attackers. By relaxing the power factor, we are able to implement sophisticated encryption algorithms at each node and thus support higher levels of security.

V. WSN ARCHITECTURES FOR ITSS

In our study of the WSN-based architectures for ITSs, we can identify two main architecture categories under which various contributions have been reported:

1. Planar (flat) architectures: in this category, a single-tiered WSN architecture is used to support an ITS. Infrastructure-less (i.e., peer-to-peer ad hoc wireless networks) communication paradigm is utilized to support inter-vehicle (V2V), communication while infrastructure-based communication paradigm supports vehicle-to-Infrastructure (V2I) communication.

2. Multi-tiered architectures: in this category, two or more tiers constitute the WSN architecture in its support of an ITS. In their support of V2V and V2I communications, these tiers maybe homogeneous (i.e., using a single technology alone), or heterogeneous (i.e., incorporating different technologies in the different tiers to achieve enhanced performance).

In the following two subsections we elaborate on these architecture categories.

A. Planar Architectures

The planar architectures is similar to the basic WSN architectures that we mentioned in Section I. The only main difference is that a planar architecture for an ITS includes mobile sensors (installed on vehicles). The advantage of this architecture is that it resembles the one already in use for the "object or target tracking" application. This means that some of the challenges encountered in such architectures are known, in spite of that ITSs are dealing with larger number of objects (i.e., vehicles) to track and monitor. On the other hand, the main drawback of this architecture is that the ITS has major constraints in terms of processing capability of the nodes. Thus, the ability of the WSN to support QoS is limited. The planar architecture is used in [40][41][42] and we describe these contributions in the following.

1) WSN-based Navigation System in WiMAX networks

This architecture (we refer to it as WNSW in the rest of the paper) is proposed in [40]. The architecture is intended to support a navigation system that determines the optimal route (that is, the route that is most economic in gasoline exhausting while achieving least travel time) to a targeted destination. This architecture is infrastructure-less and the communication paradigm of use is inter-vehicle. (V2V). The vehicles communicate on a peer-to-peer basis to exchange the required data. Therefore, the mobile stations can form a mobile ad-hoc wireless network (MANET) to exchange data. Different types of sensors are installed on each vehicle to sense the speed and direction of neighboring vehicles. Furthermore, vehicles are equipped with the IEEE 802.16 (WiMAX) network interface to exchange the traffic information with the neighboring vehicles. The usage of the latter interface is motivated by the wide range (3-5 km) of communication it provides, which enables each vehicle to collect more accurate data about the intended destination. Also, a data rate of 30 Mbps is achievable with that interface, and this eliminates any restrictions on the volume of data exchanged. Finally, GPS devices are used on each vehicle to get the longitude and latitude of its position.

2) Wireless Sensor Network for Intelligent Transportation Systems

The Wireless Sensor Network for Intelligent Transportation System (WITS) collects and communicates information to organize the traffic at intersections [41]. This architecture depends on a fixed infrastructure composed of roadside units (that is, sensors installed on both roadsides) and intersection units. The communication paradigm supports both V2I and I2V. Vehicle units (that is, vehicles equipped with sensors) send vehicle parameters (speed, direction, location, etc.) to roadside units. Roadside units work on aggregating the received data before transferring them to the intersection unit, which relays them to the final strategy sub-system. Roadside units are installed on both sides of a road in order to achieve a redundancy in sensor nodes. Furthermore, the flow of data among the roadside units (on each single side) is either upstream or downstream. Thus, with the help of the information about the position of the passing vehicles, localization of the roadside units becomes simple. We note that physical and MAC layers in this architecture support the IEEE 802.15.4 (ZigBee) standard.

3) Clustered WSN for ITS

The Clustered WSN for ITS architecture is intended to support road traffic monitoring [42]. This is a clustered architecture where each cluster is constituted of a BS (the cluster head) installed on the roadside and one or more passing by vehicles (the cluster members). Several BSs are installed on the roadside to monitor the passing traffic. Data are transferred from vehicles to the BSs (that is, V2I), from BSs to vehicles (that is, I2V) and among the BSs themselves. Vehicles are equipped with sensors while the BSs comprise mass storage memories to store a large volume of information. The existence of multiple BSs enables the WSN to tolerate faults. The failure of a certain BS should not degrade the performance of the network as several other BSs are available. Usually, BSs are separated by a 100m distance and each BS can alone monitor up to 200 vehicles. An interesting point about this architecture is the support of security. A key refreshment algorithm is applied periodically between neighboring BSs as well as between a BS and a vehicle. The BSs and the vehicle sensors perform DES-based encryption in their data communications.

4) Planar Architectures Summary

The three planar architectures use different methodologies, each addressing different problems. WNSW is infrastructure-less and avoids the overhead associated with the fixed infrastructure in terms of localization algorithms, multi-hop routing, limited power resources, costs of installations and maintenance. Depending on vehicle batteries to supply the sensors with, power is a critical advantage of this architecture. However, this architecture suffers from the ordinary problems associated with peer-to-peer networks in terms of the overhead of communications and multi-hop routing that may lead to delays and thus degradations in the QoS. The complexity of computations required by the sensors in this architecture may contribute to more delays.

On the other hand, the WITS architecture moves the burden of complex computations to the roadside and intersection sensors and thus simplifies the tasks handled by the sensors on vehicles. Also, given the fixed and defined infrastructure of the roadside and intersection units, routing will be simplified and an upper-limit on the expected delays can be pre-defined.

Finally, the clustered WSN architecture, although can provide better fusion and aggregation of data before delivering them to the final decision-making stage, it suffers from the overhead of forming the clusters themselves. Also, the use of multiple fixed BSs as cluster-heads can be costly, given that these are assumed to be bulky devices. In conclusion, we think that the architecture of WNSW can be the best candidate that provides more flexibility for ITSs.

B. Multi-Tiered Architectures

The multi-tiered architectures use hierarchical designs in order to improve the performance of the WSN in terms of delay and routing. As mentioned earlier, multi-tiered architectures may either be homogeneous, like in [46], or heterogeneous, like in [47-54]. The heterogeneous architectures couple a WSN with other technologies (like WLAN) such that higher performance can be achieved. The main target is to move the burden of handling complex processing and computations to another layer where other technologies can be more efficient than WSN. As a result, more attention can be given to support intelligent applications where QoS is a high concern. A drawback of the heterogeneous architectures is that dealing with more technologies adds to the complexity of the design. Interfacing among different technologies should be handled with extreme caution. In the following we describe the available multi-tiered architectures contributions.

1) Sensor Network with Mobile Station

The Sensor Network with Mobile Station (SNMS) architecture is proposed in [43]. The architecture is intended to support road traffic monitoring. Two tiers are used: the lower tier, which is a single-hop network constituted by sensor units and a single vehicle, and an upper tier, which is constituted by a P2P network of vehicles. The lower tier supports I2V communications while the upper tier supports a V2V communications. Sensor units, which are installed along road sides, sense various parameters like humidity, temperature and traffic situation. Vehicles are equipped with sensors that collect and aggregate the data sent by the roadside units. In other words, vehicles appear as mobile sinks in the lower tier of the architecture. Bluetooth technology is used in the lower tier to achieve short-range communications over 2.4 GHz with a bandwidth of 1 Mb/s. In the upper tier, vehicles use two modes of communication: 1) WLAN mode, in which the vehicles form a netted structure for communication, and 2) Multi-hop ad hoc network mode, in which vehicles exchange the data and route them through other vehicles.

2) Two-tiered WSN for Real-Time Communications

The Two-tiered WSN for Real-Time Communications (TTW-RTC) architecture is intended to support road traffic monitoring [44]. There are two tiers: 1) A lower tier that is a WSN constituted by vehicles equipped with sensors, and 2) An upper tier that is an overlay WLAN constituted by resourceful Access Points (APs). This overlay network serves as a backbone for the WSN. V2V is the paradigm of communication used in the lower tier while V2I communication is used in between the two tiers. The IEEE 802.15.4 (ZigBee) standard is implemented in the WSN while the IEEE 802.11 (WiFi) with the IEEE 802.11e extension is implemented in the backbone WLAN. The main advantage of this architecture is that it removes the burden of complex computations from the WSN and migrate it to the resourceful (in terms of available memory and power resources) upper tier. The latter can support a range of coverage up to 300m and a data rate of 11 Mbps (compared to < 150 m and 128 kbps, respectively, in the case of the lower tier). Also, the routing functionality that provides connectivity among all the sensors of the large WSN is handled by the APs. Furthermore, localization is highly simplified with the availability of the fixed infrastructure (APs). While the lower tier is capable of covering a range of 150m, the upper tier can go as far as 300m. The disadvantage of this architecture is that, while an AP provides critical services to the part of the WSN it covers, a failure of that AP may lead that part to lose its connectivity to the other parts of the WSN.

3) Sensor Network-Based Traffic Information Service System

The Sensor Network-based Traffic Information Service System (SNTISS) is intended for traffic information collection [45]. It has a three-tiered clustered architecture composed of: 1) A lower-tier, which is constituted by clusters of sensors responsible for the sensing and data fusion functionality, 2) A middle-tier, which is constituted by cluster-heads (or leaders) that handle management functionality beside transmission of data to terminals in the upper-tier, and 3) An upper-tier, which is the decision-making tier that is constituted by a mass data storage terminal that handles practical traffic control and service strategies based on the data collected from the other two tiers. An important aspect about this architecture is that it is a pure infrastructure-based architecture that assumes no sensors installed on the travelling vehicles. The sensor nodes (forming the clusters) are installed on both sides of each road to monitor the traffic of vehicles (the cluster-head is elected within each cluster). The data terminal node at the upper tier, given its complicated computations, is a resourceful node. As the cluster-heads consume more power than other cluster members, they are supported with a backup battery or direct wired power supply to avoid shortage of energy.

4) Multi-Tiered Architectures Summary

The three multi-tiered architectures we outlined are anticipated to provide better performance over the planar architectures by either breaking down the complex computations and distributing them over the tiers, or by migrating these computations to upper tiers where different technologies, with diverse capabilities, can support the WSN's functionality. From this perspective, the multi-tiered architectures can outperform the planar ones through providing better opportunities to support QoS. However, TTW-RTC architecture suffers, as we mentioned before, from facing certain regions of the WSN being disconnected in cases of failures in the AP. The SNTISS can be preferred over the SNMS in that it provides an accurate and generic framework and breakdown of tasks among the tiers and opens the door for different implementations of different technologies at different tiers.

VI. PERFORMANCE

In this section we show how performance is evaluated for the "Clustered WSN for ITS" architecture proposed in [42]. It is worth mentioning that the authors in [42] proposed a collision-free data link layer protocol relying on a time-multiplexed peer-to-peer communication. According to this protocol, a vehicle entering a cluster needs firstly to request a unique and unused time slot for its communications within that cluster. Arranging for a free time slot before entering the cluster guarantees a collision-free communication and supports better load balancing among the different types of messages (originating either from the vehicles (vehicle messages or the BSs (services and emergency messages)) sent over the communication medium. Furthermore, the protocol guarantees that a vehicle, roaming among different clusters, is allocated an unused timeslot by employing a time-slot refreshment algorithm. Securing peer-to-peer communications is also considered. In essence, the transmitted messages are encrypted by the DES algorithm. The encryption keys shared between the neighboring BSs themselves and between a BS and the vehicles in its cluster, are refreshed periodically.

The proposed architecture and protocols were implemented in TinyOS and simulated using TOSSIM [46]. The simulations considered cluster-heads situated at 100 m apart. Such a distance allows for coverage of a maximal number of vehicles while avoiding any overlap among clusters. Each cluster is initially associated with several vehicles traveling at 100 km/hour over a 2 km long road. The performance was compared against that of tinysec [46] and the standard Public Key Infrastructure (PKI) signature scheme [47]. Figure 2 depicts the performance in terms of the achieved throughput (in bits/s) given a certain number of vehicles. It is clear that the proposed algorithm achieves better throughputs than the other algorithms. However, as the number of vehicles exceeds 170 the throughput starts decreasing. The latter is due to the overhead associated with the encryption algorithm used.

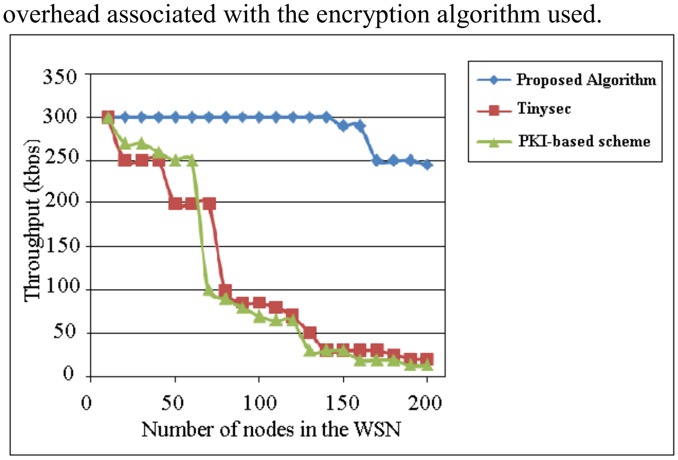

Fig. 2: Algorithm performance: Throughput versus the number of communicating nodes moving at speed of 100 km/hr for services messages.

VII. CONCLUSION

In this paper, we provided a general overview of the opportunities provided by WSNs to support an efficient ITS. We discussed the important parameters that drive the design of any WSN architecture and showed how these parameters can be relaxed or simplified in the case of ITSs. We have also reviewed some major contributions available in the literature towards building effective WSN-base ITS. By categorizing these architectures into planar and multi-tiered ones we could see the diverse strengths and weaknesses that are associated with the different architectures. The main conclusion we draw from this research is that multi-tiered architecture can show promising performance, over the planar architectures, since they can alleviate the problems associated with constraints in the WSNs, in terms of power and complexity of processing, by incorporating more tiers and different technologies, with different capabilities, at each tier.

We are planning to focus on devising WSN-based architectures of ITS that can provide more support to security. Indeed, security is critical in ITS because compromising a node or a set of nodes in a WSN can lead to the injection of false data to provide travelers with wrong information about the conditions of the roads. The latter may be used by intruders to divert the traffic away from certain regions of robbery attacks (against banks for example). This means that security should be treated carefully in the design of any ITS architecture.

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