Evaluation of a Proposed Intelligent Transportation Framework using Computer Network Concepts: A Case Study for Hajj-Pilgrim Traffic Monitoring and Control

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Abstract

Intelligent Transportation Systems (ITS) provides an effective mechanism by which to optimize the movement of people/vehicles in congested and densely populated areas. The ITS infrastructure integrates modern sensory-communication systems together with computational techniques to provide the processing functionality required in such intelligent systems. An approach for incorporating intelligence in transportation for a candidate application-domain is proposed in this paper for the case of the Hajj traffic scenario. In particular, this paper addresses the need to optimize the movement of pilgrim-traffic between Holy sites during the Hajj period which clearly demonstrates its key significance for the well-being of around three-million pilgrims each year. Computational modeling and networking techniques were employed for behavioral analysis of the traffic-congestion domain with extensive simulations performed to evaluate the proposed ITS deployment scenario. The technique is found to be very effective for addressing the transportation-bottleneck that arises as a result of the saturated and congested roads at known 'hotspots' between Holy sites. It is shown that the proposed monitoring and control approach of traffic results with reduced congestion-levels, lower-journey-times and an overall enhancement of the transport-infrastructure capacity utilization. Finally, vehicle-flow trajectories are examined and optimized in order to increase traffic-throughput and reduce traffic-delays under the environmental-constraints of the target deployment site.

Keywords: *Intelligent transportation systems, modeling and simulation, road-network traffic evaluation, traffic-management optimization.*

1. Introduction

Hajj is the Islamic annual pilgrimage to Makkah and the Holy sites surrounding Makkah (including Mina, Arafat and Muzdalifah). The Hajj gathers over three-million pilgrims worldwide in order to complete a once-a-lifetime religious obligation [1]. Pilgrims gather for a short period of time, five to six days in total, in which to complete the Hajj rituals (during specified days of the 12th month of the Islamic lunar calendar) at Holy sites within the very limited spaces and geographical boundaries of the Holy city.

These days come on the 8th to 12th or 13th of the twelfth month of the Islamic lunar calendar. Moreover, pilgrims move from one Holy site to another within a restricted time. Fig. 1, (map is not to scale and is a representation only), shows the relative proximity of the Holy sites and the journey undertaken by pilgrims. Therefore, all pilgrim services provided are required to be carefully planned. For instance, among those services is the need for traffic-congestion avoidance and control for vehicles and pedestrians, which is an issue of particular importance in this paper.

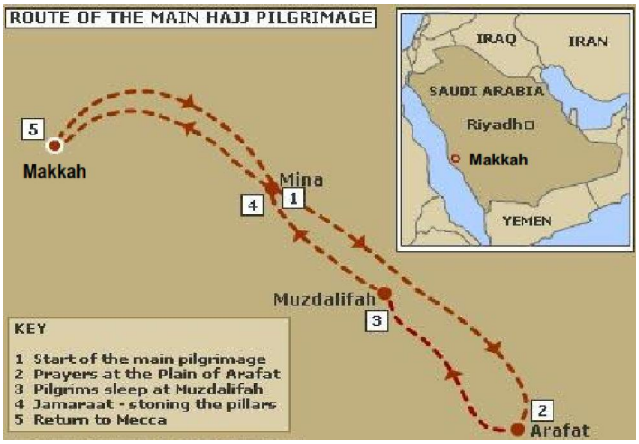

Fig. 1: Main route undertaken during the Hajj pilgrimage - Modified source image from [2].

A number of unique characteristics of the pilgrimage can be found in the pilgrims who attend Hajj, the places of gathering and the nature of rituals performed. Furthermore, environmental-issues at the Holy sites have been found to encompass a number of challenges including [3]:

- the fixed underlying road-network infrastructure,

- the limited-capacity versus demand of the interconnecting road-network,
- safety issues,
- socio-economic and behavioral factors as well as other background factors.

Essentially, those characteristics and constraints pose a number of different challenges for Hajj authorities responsible for controlling crowd movements and the general well-being of pilgrims. Although it was previously noted that the annual-Hajj spans over a period of 5-6 days, it is however, very important for Hajj planners and researchers to understand that Hajj rituals are scheduled and set within the requirements of the religion (e.g. preset timings for each Hajj action/ritual) in such a way that results with all pilgrims moving together between Holy sites at common specified days and nights. Table 1 summarizes the daily Hajj schedule for pilgrim movements and activity, while Table 2 shows the approximate distances between Holy sites.

Table 1: Abstracted Daily Schedule of Hajj

No.	Date during the 12th Islamic month.	Place (Holy Site)
1	8th (day and night)	Mina
2	9th dusk to sunset)	Arafat
3	9th (night to 10th before sunrise)- It is allowed for some cases to move earlier.	Muzdalifah
4	10th after sunrise to 12th or 13th before sunset	Mina
5	After 12th or 13th to Makkah	Makkah

Table 2: Approximate distances between Holy sites

From	To	Approximate Distance
Makkah (Haram)	Mina	8 Km
Mina	Arafat	14 Km
Arafat	Muzdalifah	9 Km

It is from the experience of the authors that the most critical task in traffic planning for Hajj (see Table 1), is to facilitate the transfer of all pilgrims from Mina to Arafat before noon of the 9th day, or around 2 hours before sunrise of the 9th day in the worst case. The scenario is further exacerbated with the continuous traffic jams which result in very complicated consequences for pilgrims and Hajj authorities.

The objective of this work is to evaluate congestive bottleneck regions in the Makkah road-network interconnecting the Holy sites during Hajj using computational modeling techniques and principles of queuing networks. In particular, modeling techniques are used to simulate the Makkah road network as a queuing system with domain-specific characteristics. Significantly, the developed model should provide Hajj authorities with an efficient approach for behavior-analysis of the traffic congestion 'hotspots' between Holy sites enabling traffic-management decisions to be optimized 'on-the-fly'. With this approach, possible key benefits are obtained using a distributed scheme to traffic management, including; improved utilization of the road-network infrastructure. Moreover, additional benefits are evident in its support for updating the system to accommodate variations in traffic statistics recorded over many years (as model inputs) for predictability-analysis of future traffic trajectories. Optimal traffic management decisions/cases could be modeled prior to implementing any change in reality, thereby resulting in time, cost, and resource optimization by removing the need for continuous development work at the site-of-interest. This paper focuses on developing a congestion-aware transportation-system for pilgrim-traffic on the Makkah road-network during the Hajj season.

The remainder of this paper is organized as follows. Section 2 presents the literature survey, Section 3 describes the methodology, Section 4 explains the implementation and Section 5 demonstrates the results of the extensive simulations conducted to simulate the evaluation of the Wireless Sensor Network-based Hajj-transportation system. Finally, Section 6 concludes the paper.

2. Literature Survey

Similar challenges have been given significant attention in the literature, with numerous wireless communication technologies being applied to address similar/related requirements in various domain-settings. Notably, the use of Global-Positioning Systems (GPS) and Radio Frequency Identification (RFID) technology were previously employed for purposes of vehicular traffic monitoring [4 - 5]. The use of passive-RFID technology for pilgrim monitoring during Hajj was then presented in [6 - 7]. More recently, the use of WSNs in the context of intelligent transportation systems (ITS) was proposed in the literature for facilitating efficient traffic movements [3] [8 - 17].

An Intelligent Transportation System (ITS) uses computational advancements in IT to improve the efficiency of existing and new transportation systems through the deployment of surveillance and tracking technologies for continuous monitoring of traffic conditions. Advantageously, ITS is employed to resolve traffic congestion problems in addition to providing

solutions for other traffic-related applications, including; vehicular parking management, reporting emergency scenarios, vehicular navigation, propagation of traffic conditions on highways, providing traveler information, collision-avoidance and improving driver safety [8]. ITS-related projects have received significant worldwide attention and funding from various sectors including funding by educational-institutions and governmentally funded projects, examples of which can be found in [8, 14 – 15, 18].

The idea and framework for using a WSN-based ITS for efficient Hajj traffic monitoring and control was introduced in [3]. In [3], the proposed traffic control WSN-ITS system consists of the deployment of wireless sensor devices capable of receiving, processing and transmitting environmental data; and base-stations responsible for collecting the raw sensory-data and forwarding the data on towards a central control system for computing traffic management decisions based on the actual road-network state.

This paper develops a proof-of-concept for the Hajj WSN-ITS system through the use of computational modeling and computer networking techniques to provide analysts with a key role of optimizing traffic-management decisions taken at the deployment site upon receiving the dynamically varying monitored-data of the traffic state.

3. Methodology

This paper employs queuing networks and polling concepts in order to develop a computational model of pilgrim-traffic movements between Holy-sites at selected regions within the Makkah road-network during Hajj. By examining the scenario considered in this paper, the regions-of-interest can be characterized by a recurring trend/pattern, whereby a number of frequently used road sections converge onto a single road (or fewer roads) en route to the destination site or as a point-of-entry to the Holy-site. A simple queuing/polling model can be developed using a number of queues/access-points competing for access to a shared (single server) resource. However, it is noted that in practice, the proposed traffic-management approach requires the physical deployment of a wireless sensor network in order to supply the ITS with real-time live data of the traffic state, with data being processed to compute a traffic-management decision. The WSN-based ITS deployment scenario is illustrated in Fig. 2; highlighting that sensory data is collected and forwarded to the central management system for computing traffic-management decisions.

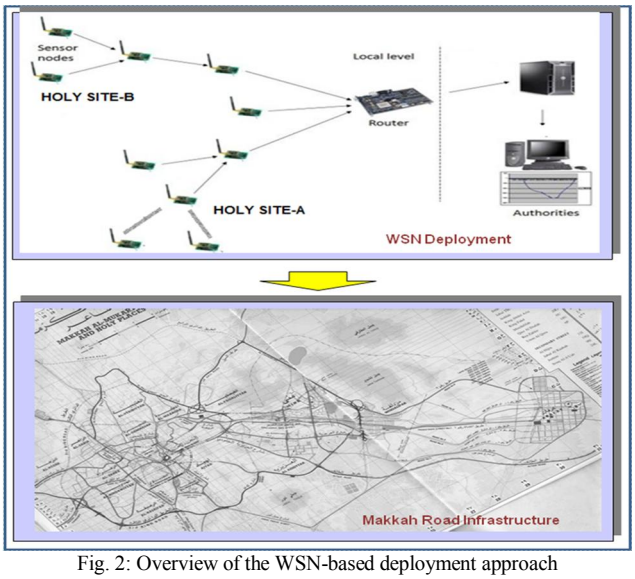

Fig. 2: Overview of the WSN-based deployment approach

The model described in this paper resembles the proposed system in [3] except that this model removes the need for circulating traffic-flow request data in the network since the model presented here simply relies on the sensory-data gathered in each data-measurement cycle in order to compute traffic-flow decisions. Therefore, to evaluate the proposed pilgrims-traffic movement several assumptions were made these assumptions include:

- The stochastic multi-queue model consists of a number of source generators with constant and variable arrival rates at each source to represent the continuous nature of incoming traffic observed from converging roads during Hajj.
- Pilgrim-vehicles are modeled as fixed-length container objects in the model.
- Source generation processes use a blocking mechanism, whereby incoming traffic can be temporarily halted until some buffer space become available to accommodate further traffic.
- Switch-over and service-time distributions were kept equal over all queues.
- A queue-occupancy threshold parameter was considered for each converging road to account for varying dimensions/characteristics of road designs.
- A dynamic service-order discipline of the queues is employed based on the queue-occupancy parameter.
- All roads en route from a source to a destination site are considered to accommodate unidirectional traffic only.
- No vehicular-traffic was assumed to block the server; thereby removing the ambiguity of unknown server processing and switch-over times between queues.

4. Implementation

This paper aims to model a sample recurring scenario within the Makkah road-network in which a number of convergent roads intersect with a main road en. route to a destination site. In particular, this paper focuses on one such region-of-interest encountered from Mina en. route to Arafat during Hajj. In the proposed approach, access fairness between competing convergent roads is achieved by regulating vehicular traffic-flow using a distributed view of the queue loadings. In practice, the model described here would be applied as a medium-access sub-layer that uses the statistical data obtained from the WSN for intelligently controlling traffic-light signals at intersection points of convergent nodes. Control decisions can be made using an order of service of the competing access-nodes either manually, or by automation according to the dynamically changing state-information, as was the approach used in this paper.

4.1 System Operation

The operation of the developed system/model can be described as follows. Initially, the sensory-data obtained by the WSN infrastructure - modeled by the source-generation processes - would be supplied into the system in order to represent the state of arrivals into each convergent node. Queue-occupancy information at each node is then used for service-selection. Next, a number of vehicles is removed from the most eligible queue and transported towards the destination as specified by the gated-limit parameter upon each service. Service is then given to the next selected node following a switch-over time that accounts for clearance times of vehicles previously with the server. It is noticed that the polling system described here resembles many random polling schemes employed for modeling stochastic data-traffic networks from the computer networking literature [19, 20].

5. Simulation Results

This section presents an evaluation of the ITS system in the context of Hajj vehicular-traffic at particularly congested points along the Makkah road network that are identified as the region-of-interest in this study. The three figures of merit used in this paper are the mean system latency; e.g. the average delay encountered by vehicles from the point of entry into the system to the point of exit from the system, the mean system throughput; considered as the number of vehicles that had exited the system per unit time, and the source-blocking probability; defined as the ratio of blocked vehicles at source/site nodes over the number of vehicles that had entered into the system.

Extensive discrete-event simulations were conducted using the OMNeT++ development framework. The effects of varying the number of variables, including; the source arrival rate at each node, the gated-limit (duration of service-visits at each queue) and the queue-capacity threshold were considered to obtain a detailed analysis of the congestion-aware transportation system. Reaching the threshold at any queue had caused the corresponding source/generator to block until some space became available at the queue.

Simulation results had demonstrated that as the queue-arrival rates (system load) increased, the mean system latencies, Fig. 3, experienced by pilgrim-vehicles had steadily increased for lower load values until the point of saturation in the queue loadings was reached, beyond which the mean latency had increased at a rapid rate for most values of the gated-limit.

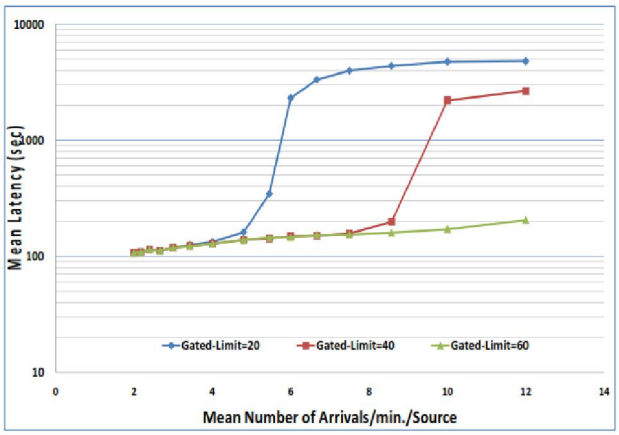

Fig. 3: Mean latency of pilgrim-vehicles at a region of interest.

Furthermore, it was shown that increased efficiency could be achieved at higher loads by using higher gated-limits upon each service. Traffic throughputs were also shown to possess behavior relative to the system load and gated-limit values used, Fig. 4.

In particular, higher system throughputs were obtained at higher loads when using higher gated-limit values. In Fig. 5, the effect of the gated-limit values at various system (input) loads was illustrated. It was shown that a negative effect on system performance had occurred at high loads using lower gated-limits. This can be explained by the frequent and excessive switch-overs (and consequent delays incurred) between the converging nodes at higher system loads. Finally, not shown in the graphs, was the expectation that increasing the queuing

capacity would cause increased average vehicle system latencies.

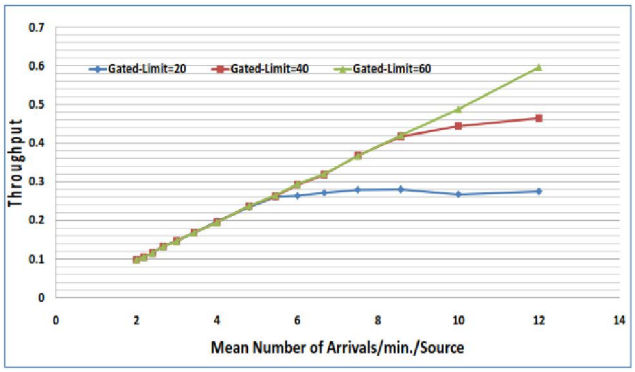

Fig. 4: System throughput of pilgrim-vehicles at a region of interest

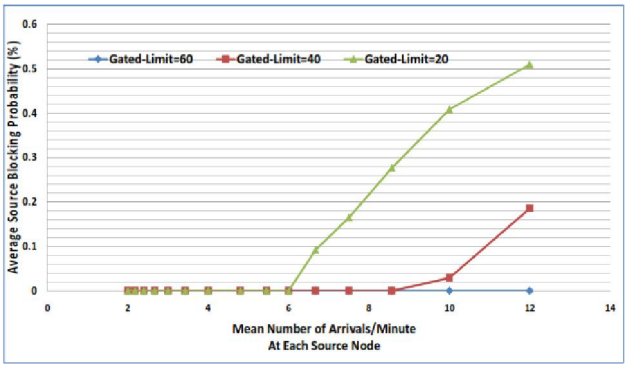

Fig. 5: Source blocking probabilities at source nodes generating incoming vehicular traffic.

The results had demonstrated the ability to apply computer networking concepts for evaluation purposes in order to achieve an enhanced transport-infrastructure capacity utilization using a WSN-based ITS deployed onto the Makkah road-network using higher gated-limits at congested regions for optimal performance conditions to be satisfied.

6. Conclusion

This paper has investigated a fair access transportation system for Makkah's road network between the Holy sites during the annual Hajj season. The paper described the development of a model based on queuing and networking concepts, achieving effective traffic-congestion awareness and resolution, in which the state information for convergent roads at intersection points are monitored to provide analysts with a greater insight of the overall system state. Finally, the developed model demonstrated how a WSN-based ITS system utilizing a congestion-aware algorithm could be used to provide a state-of-the-art system that provides a comprehensive solution for the monitoring and control of pilgrim-traffic movements during Hajj.

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