A Proposed Model for Optimizing the Flow of Pilgrims between Holy Sites During Hajj Using Traffic Congestion Control

Omar Tayan
{olayan@taibahu.edu.sa}
College of Computer Science and Engineering, Department of Computer Science, Taibah University, K.S.A.

Abstract— The use of computer simulations for modeling the behavior of pre-existing/inaccessible products/real-life scenarios is increasing in academia and industry. The advantages of computer modeling and simulation are numerous, and include; controlled experimentation on a pre-existing/in-accessible real-life scenario without disturbing the real-life system, time- and space-compression of a real-life system and sensitivity analysis of selected key parameters. The need for such advanced computational techniques for behavioral analysis is increasing in the domain of traffic congestion and control, which has particular significance in an attempt to optimize the movement/flow of traffic in various applications. This study is particularly concerned with optimizing the flow of pilgrims between Holy sites during the Hajj period, which remains a relatively unexplored optimization problem of key significance for the well-being of approximately three-million people each year. The aim of this study is to introduce a new model for optimizing the flow/transportation of pilgrims between the various Holy sites through the deployment of existing techniques in a new application-domain. Mature computer-science literature are considered here for modeling the Makkah road network using the widely applicable concept of queuing and polling systems from computer science and engineering. A further contribution of this paper is that key benefits are obtained by employing a distributed approach to traffic management, including increased efficiency of the available road network, thereby resulting with a decrease in the delays encountered and pollution emitted as a consequence of the inefficient flow of traffic.

Index Term-- congestion-awareness algorithm, congestion control, modeling, wireless sensor network application.

Hence, computer modeling and simulation is an attractive option and is particularly well-suited for numerous applications that include: banks, hospitals, airports, manufacturing systems, and computer and communication systems. The importance of computer modeling and simulation is that they can be used to optimize management decisions made prior to implementing any change in a real-life scenario/artifact, thereby resulting in cost, time and resource optimization. The need for such advanced computational techniques for behavioral analysis is increasing in the domain of traffic congestion and control, which has particular significance in the attempt to optimize the movement/flow of pilgrims between Holy sites on the Makkah road network during the Hajj period. The following sections provide an overview description of the problem domain, the applied methodology and a proposed model for the design and implementation of a fair congestion-aware access protocol for potential deployment onto key sites during the annual Hajj.

II. MOTIVATION AND OVERVIEW

A key aim of this study is to introduce models that optimize the flow/transportation of pilgrims between the various Holy sites through the use of sophisticated computer modeling and simulation techniques. Modeling techniques are considered here in order to simulate the Makkah road network using the widely applicable concept of queuing and polling systems from computer science and engineering. The use of such modeling techniques in this study is imperative, thereby allowing much of the relevant computer networking literature, including standard and adapted/optimized protocols, to be applied with great effect in this study. Makkah’s road network can then be modeled with the application of standard/optimized and novel medium access (fairness) protocols, in which multiple access points onto the road network are modeled as nodes/queues in the queuing system that compete for access to some shared resource (modeled as servers). For example, an example of this scenario is observed (Fig. 1) when several branch roads converge into a single road/fewer roads.

1 In reality, wireless sensor networks (WSNs) would be employed to measure the traffic levels at traffic points - illustrated using red circles in Fig. 2.
The study compares a number of potential transport protocols suitable for the Hajj environment, before justifying the most appropriate/efficient protocol that optimizes the flow of pilgrims between the various Holy sites. Hence, it is evident that this study is highly significant in any effort to manage the traffic flow of pilgrims and therefore provides much potential for application. Key benefits would be obtained by employing a distributed scheme to traffic management, including increased efficiency of the available road network, thereby resulting with a decrease in the delays encountered and pollution emitted as a consequence of the inefficient flow of traffic.

A number of related research-approaches have been considered for the problem of traffic management, with the most notable being the use of traffic lights with sensor devices that open the gate for incoming traffic based on some parameter value [1]. Such an approach is comparable to intermediate routing in a queuing system. On the contrary, the model presented here applies the concept of queuing systems in order to evaluate a novel distributed approach that provides a medium access (fairness) mechanism for traffic at key entry points in addition to intermediate points within the road network. This study aims to investigate the performance of various protocols in terms of achieving the most efficient/optimal road access/utilization mechanism, in which performance is considered as the average waiting times of pilgrims within each queue and within the system as a whole from the point of entry to the point of exit on the road network. Hence, this study focuses on congestion awareness algorithms for Hajj traffic on the Makkah road network.

III. METHODOLOGY AND DESIGN

This study considers the use of queuing and polling systems in order to construct an abstract model of the traffic flow between Holy-sites in Makkah during the Hajj season. The following discussion examines the significance of queuing and polling systems in this study.

Polling systems have been studied extensively since several decades ago, and consequently, a rich source of knowledge has emerged in the use of polling models for a variety of applications. Polling is a process whereby a token/query is issued and broadcast to all networked nodes in order to receive status information of each node [2] and thereby determine which node is most eligible for access to a shared-medium based on some medium-access control scheme. Essentially, all polling systems consist of a single source that is shared between multiple access queues [3, 4]. Fig. 2 shows a similar scenario in the study of Hajj traffic flow and congestion control, whereby many frequently used sections in the road network involve numerous roads merging into a single road as a point-of-entry into a particular site.

A large number of studies can be found on the use of polling systems to model a variety of applications in many disciplines. Much literature exists on the use of polling systems for modeling token-passing communication networks with various polling schemes [2, 14], and is also found in the modeling of more general applications involving the 'multiple-access' problem for a shared resource [13]. In all the relevant literature surveyed, polling systems were broadly classified according to following characteristics that include [4, 8, 9]; continuous- or discrete-time systems, queuing buffer capacity, queue service discipline, switch-over times, symmetric or asymmetric properties, cyclic/non-cyclic service order discipline, exact or approximate analysis. The characteristics of the polling system used to model the Hajj traffic scenario is considered in more detail.

First, the polling system comprises a number of source generation processes to represent the incoming arrival traffic.
classified as discrete-event arrivals. The exhaustive (followed by the gated scheme) is the most efficient service discipline when finite queue-lengths are used (as required in this study). Polling systems are associated with server switch-over times that correspond to the time interval between the service completion time at a queue, and the consequent arrival time of the free token at the next transmitting queue. In this study, the arrival rates, service time distributions, and switch-over time distributions are non-uniform between queues as in an asymmetric system.

Cyclic service-order disciplines are used by the server to allow data-gathering/request packets to rotate between the competing stations in order to collate current queue occupancy values, rate-of-arrivals, rate-of-departures etc statistics from each station. Cyclic polling systems employ a round-robin algorithm and a single server that serves multiple container objects (gated or exhaustive disciplines) on each queue visit. On the other hand, a non-cyclic service-order discipline is required to serve queues randomly, based on station requests for instance. Hence, the dynamic service-order of queues can be classified as a probabilistic polling scheme employing distributed and stochastic algorithms, depending on the system state. For instance, a service policy of particular interest in this study is to observe the contents of each queue with the decision of service allocation determined based on the highest queue occupancy. An advantage of dynamic service orders is that they are sensitive to the actual system state.

An alternative approach to dynamic service orders would be to employ queue priority schemes. Queue service mechanisms permit the prioritization of queues according to key design parameters, thereby achieving improved system performance. Important design parameters in such systems include: visit order used, the frequency and duration of visits at queues and the order of packet/message service within each queue.

The operation of the proposed polling system is as follows. Initially, the study aims to focus on modeling the convergence of the road network from Mina to Arafat, followed by Arafat to Muzdalifah, pending on the availability of statistical data. However, it is noted that the convergence scenario could be modeled more generally by observing that any number of converging roads (modeled as queues or stations/nodes) compete for access to a single/fewer point(s) of entry, as in a cyclic interconnection of nodes towards a single/fewer server(s). Thereafter, a request packet circulates through the network of stations/nodes in a cyclic discipline in order to obtain the necessary statistical data representing the state of each node. The data collected describing the state of the system is then used to serve a particular queue based on queue-occupancy. Evidently, the engineering characteristics/design of Makkah’s roads between particular sites-of-interest have a significant effect on the design of the model. For instance, as the width of any convergent road increases (as in the left of Fig. 2), the queue lengths decrease before attaining the same queue-occupancy threshold. This scenario effectively demonstrates the case where each road may possess multiple lanes of traffic. Hence, for purposes of medium access fairness, this study considers the queue-occupancy values/threshold without regard to the queue-lengths in order to account for the varying dimensions of road designs. As the circulating packet updates the state information, the system determines the most eligible queue or service on the next switch-over. Notably, the stochastic service discipline employed resembles the random polling schemes used in many stochastic data-traffic computer-network models [8].

IV. DESIGN AND IMPLEMENTATION

In the proposed protocol, access fairness to the road resources is achieved by regulating traffic flow using a distributed view of the queue loadings, whereby all affected nodes are able to support/oppose required queue-flow services [5, 8, 9]. Hence, the queuing model implementation must allow intermediate nodes to decide whether they support or oppose/reject each proposed queue-flow. The protocol would then accept or reject, the proposed queue-flow by considering its own local perception of the loading at the queue and the stance taken by each affected node. Advantageously, distributed protocols can be employed to establish queue-flow request services, thereby removing the need for a central management node. In this approach, the packet request structure consists of M partitions, each corresponding to one node, with the request packet circulating between the road access points as in a logical interconnection of ring nodes (Fig. 3). Each partition is an N-bit binary counter that counts the number of opposition-nodes encountered by each (queue/station) flow request. N is the bit-length of each request in the request field of the packet, relative to the queuing-network size, 2^{N−1}. Hence, an N-bit counter is required for each node in a 2^{N−1}-node circular-road access network, where each subfield is initialized to the reset state (e.g. 000 for an interconnection of 4-nodes), indicating no requests waiting. Fig. 3 illustrates the request-token/packet format that circulates between converging roads/nodes, designated for use with inter-connected communicating wireless sensor nodes and base stations. In practice, the proposed congestion-awareness protocol would then be applied as the medium access sub-layer that uses statistical data obtained from the wireless sensor nodes for intelligently

---

Fig. 3. Token-format that circulates between converging road access-points.
controlling traffic light signals between the competing access points. Therefore, the main hardware requirements incurred here would involve the costs for the wireless sensor network, comprising wireless sensor nodes and base/field stations, connected to an end-user/server for data-processing and data-storage/retrieval. A similar concept of employing wireless sensor networks for data-monitoring applications has previously emerged in the literature and include; vehicle monitoring applications [15], industrial-monitoring applications [16] and wild-land cultural heritage sites monitoring [17].

When a node transmits a connection request, it sets its subfield to a binary 100. A reset value (000) at the request field is only obtained at initialization or when no request was sent; the reset value (000) cannot otherwise be obtained regardless of the number of rejections made. Each reject-request on a request subtracts from the correct value of the field associated with the request. Hence, the maximum number of rejections made on any request would only reduce the request subfield to 001. A clear benefit of this approach is that the cell collects more management information regarding the state of the network nodes as it circulates through the ring. Furthermore, by counting the number of rejections on each request, it has become possible to consider other factors for deciding upon flow-request acceptance or rejection at each source-node/queue-access-point. For example, in a network whose access nodes are prioritized, it may be necessary that high priority nodes/access-points are able to proceed with a flow-request acceptance even after a majority of nodes have rejected the request. Hence, this approach provides a distributed-view of the state of competing roads/stations through control/management information from the sensor nodes deployed at access-points to a shared road. Thereafter, a decision can be made on an order of service of the competing access-stations/queues (either manually or using automation) according to some selected parameter(s) such as instantaneous and average queue-lengths or average queuing-delays for instance.

This section also proposes an enhanced extension of the above congestion-awareness protocol which conveys precise details of nodes with opposing signals for each flow-request in the system. Advantageously, such a system enables precise data-gathering statistics regarding the state of each node at any point in time. However, the resultant complex request-packet structure associated with this protocol entails the drawbacks of significantly extra logic (electronic) circuitry for processing, loss of simplicity and increased-costs, rendering this enhanced protocol less-efficient overall for the target application-domain.

V. DISCUSSION AND CONCLUSION

The previous section has described a new approach that provides a traffic-congestion awareness protocol, in which the number of rejections on each queue-flow request is monitored to yield a greater insight of the state of each node. Initial work on the congestion-awareness protocol considers the effect of varying the number of proposed node-rejections for each queue-flow request before blocking the request, the effect of varying queue-thresholds (maximum permitted number of container objects before requesting to release traffic - 'queue-flow'), and the effect of varying the number of container objects to release following a queue-flow request acceptance. It is expected that as the queue-loadings and queue-arrival rates increase, more nodes shall propose to reject other queue-flow requests in order to prevent their queues exceeding the queue-threshold. Furthermore, it is expected that if the rejection-threshold was increased (such that more proposed rejections are required for each queue-flow in order to block the request), traffic throughput would also increase with a slight increase of the mean delay at each node/queue. An increase in the queue-length threshold was expected to yield an increase in the mean queuing delays encountered, whilst reducing the number of proposed rejections for each queue-flow request.

In short, this study has investigated access control and fairness protocol for Makkah’s road network between Holy sites during the significant annual event of Hajj. A fair mechanism of controlling road access and preventing node starvation, whilst limiting the delay in the network could be achieved using the proposed traffic congestion-awareness protocol.

REFERENCES

