Cloud-based Context-aware Mobile Applications and Framework for Hajj and Umrah Management

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Abstract *Hajj and Umrah are holy events performed by millions of Muslim pilgrims every year. Management of such events is a real challenge. This paper proposes a modular framework for the distributed management of those events. In this framework, a cloud-based global server is used to communicate general information with a pilgrim mobile application. On the other hand, each campaign is assigned a cloud-based campaign server for communicating its campaign-specific information with its corresponding pilgrim applications. In both cases, information is communicated in each pilgrim language. The pilgrim application can also provide small-size static information. Additionally, a campaign manager mobile application allows each manager to define rules for communicating campaign-specific information in a context-aware fashion even though those managers typically lack programming capabilities. Constraints are enforced on the developed rules to help avoid errors. The system provides location-based services unachievable using Google Maps. Empirical evaluation has shown extreme satisfaction of past and potential pilgrims with the capabilities of the pilgrim application and the high usability of the manager application.*

Keywords — *Context-awareness, Distributed systems, Hajj, Mobile applications, Mobile cloud computing, Pilgrims, Umrah.*

I. INTRODUCTION

Hajj is one of the five pillars of Islam (in addition to faith in Allah and Muhammad, five daily prayers, fastening in Ramadan and paying the Zakat charity annually). It is mandatory that every (physically and financially) capable adult Muslim perform it at least once during lifetime. Additionally, a Muslim believes that an effectively performed Hajj without any evil commitment results in erasing all sins as if the pilgrim has just been born. Umrah is also rewarding and results in erasing numerous sins [1, 2]. For those reasons, millions of Muslims from all over the world perform Hajj and Umrah every year. Hajj is considered the largest human gathering in the world. For example, over 1.8 million pilgrims performed Hajj in 2106 [3]. It is estimated that 2.5 million pilgrims will perform Hajj and 15 million will perform Umrah in 2020 [4].

It is obvious that managing such enormous human gatherings is overly complex. The complexity is not only because of the large number, but also because of many other factors including the difference in languages and cultures. What complicates managing those holy events more is the extremely large number of campaigns or maktabs[1] that host and guide groups of pilgrims. Those campaigns typically have different schedules such as different visiting times to Al-Jamart pillars during Hajj to balance the distribution of the number of pilgrims going there throughout the valid ritual time. This is in addition to the several varieties of the rituals performed in Umrah or Hajj even between the pilgrims of the same campaign. Most research studies assume Hajj and Umrah events are controlled centrally by the Hajj and Umrah authorities, which is obviously an impractical assumption. This central management implies that only general information can be communicated (such as how to perform specific rituals or alerts in case of emergencies). The contributions of the paper to face those challenges can be summarized as follows:

- Considering management of the pilgrims of each campaign and communicating campaign-specific information with them independently. To the best of our knowledge, researchers have overlooked this problem in the literature in spite of its ultimate importance.
- Proposing a modular framework for the distributed management of the holy events. This framework balances services among a pilgrim mobile application that provides small-size static services, a cloud-based global server managed by the Hajj and Umrah authorities for communicating general information with the pilgrim application, and a cloud-based campaign server to communicate campaign-specific information with the application; both in each pilgrim language.

[1] We use the terms *campaigns* and *maktabs* interchangeably in this paper.

- Developing a campaign manager mobile application that allows each manager to conveniently develop rules of various complexity levels for communicating campaign-specific information with the corresponding pilgrim applications in a context-aware fashion even if those managers lack programming capabilities. The application has more advanced capabilities than similar ones in the literature. Additionally, it automatically applies constraints on the developed rules to help avoid errors.

In Mina and Arafat, each campaign is assigned a location during Hajj every year. Figures 1 and 2 show map and satellite views of Mina and Arafat respectively. The satellite view in Figure 1 shows the locations of the campaigns in Mina. A major problem is that most of those locations are unidentified on Google Maps. For example, the location of *Maktab 40 Camp 32/204* (the camp of campaign 40) [5] shown in the zoomed-in satellite view of Mina in Figure 3 cannot be searched and located using its title (name) on Google Maps. In the proposed framework, a database is maintained with information about those locations and the corresponding GPS coordinates. The contributions of the paper can be summarized as follows:

- Providing various means for location specification including circular and polygon areas on Google Maps and selection from the locations database.
- Utilizing the locations database for recommended routing within Mina and Arafat with speedup in situations such as detours.
- Providing detailed routing information based on the database, which are unachievable by merely using Google Maps.
- Allowing pilgrims to query current location in those holy areas based on the nearest location in the locations database.

The following sections of the paper are as follows: Section II provides background about Hajj and Umrah activities. Section III discusses related Hajj and Umrah research in the literature. Section IV presents the details of the proposed mobile applications and the corresponding Hajj and Umrah management framework. Section V discusses locations-based services in the framework. Section VI presents the results of the evaluation of a prototype implementation of the proposed framework. Finally, section VII presents the paper conclusion and intended future research.

II. About Hajj and Umrah

Hajj and Umrah [1, 2] are Islamic events that Muslim pilgrims perform in Mecca, Saudi Arabia. Pilgrims can perform an Umrah at any time during the year. It involves many activities including rotating around Al-Masjid Al-Haram (the Holy Kaaba) seven times, praying and traveling back and forth between Al-Safa and Al-Marwa mountains seven times. Though an Umrah can be performed in a couple of hours, the Umrah pilgrims typically stay several days in Mecca to pray in Al-Masjid Al-Haram since they believe that praying there is one hundred thousand times more rewarding than praying anywhere else. Most Umrah pilgrims also travel to Al-Madinah to visit Prophet Mohammad's tomb and pray in Al-Masjid Al-Nabawi since they believe that praying there is one thousand times more rewarding than praying elsewhere. Pilgrims can make this visit before or after Umrah.

Hajj, on the other hand can be performed only once per year in specific days of Dhul-Hijjah[2]. It requires longer time in comparison to Umrah, because it involves performing many activities in Mecca (possibly in addition to visiting Al-Masjid Al-Nabawi similar to Umrah). A typical Hajj involves the following activities in Mecca:

- On the 7th of Dhul-Hijjah: visiting Al-Masjid Al-Haram to accomplish Umrah
- On the 8th of Dhul-Hijjah: Moving to Mina to stay there the second day
- On the 9th of Dhul-Hijjah: Moving to ar-Rahmah Mountain (in Arafat) to pray until sunset and then moving to Al-Muzdalifah to spend part of the night praying and collecting small stones and then going back to Mina before sunrise
- On the 10th and 11th of Dhul-Hijjah: Going to throw the stones at Al-Jamart pillars
- To terminate Hajj: going back to rotate around Al-Masjid Al-Haram

Those are the activities of a typical Hajj since there are several ways to perform it. In general, there are three main verities of Hajj: *Tamattua*, *Qiraan* and *Ifraad*. The Ifraad is the most basic form of Hajj. The Tamattua and Qiraan involve more activities such as sacrificing an animal (such as a sheep or a goat). In the Qiraan, the pilgrim combines Hajj and Umrah; while in the Tamattua, the pilgrim performs both Hajj and Umrah without combination.

III. Hajj and Umrah Research

Relatively few research studies in the literature have been concerned with Hajj and Umrah management. Some researchers addressed the problem of the identification and tracking of pilgrims. For example, Mohandes proposed using a Passive Radio Frequency Identification (RFID) wristband for this purpose. Scanning such a tag using a handheld reader displays all corresponding pilgrim's information. This is in addition to proposing active RFID tags to report pretend pilgrims leaving the holy area [6]. An alternative approach involves providing each pilgrim with a battery-powered sensor unit including a Global

[2] Dhul-Hijjah is the last month of the Islamic calendar

Positioning System (GPS) component and a microcontroller in addition to an antenna. The unit can communicate with a wireless sensor network that covers the holy area in order to send its Id and GPS coordinates in addition to the corresponding timestamp [7]. Other researchers exploited mobile phones for the same purpose, in which case communication is with a server [8]. A research study was concerned with the problem of mobile GPS coordinates inaccuracy by exploiting historical information about the locations of the pilgrims in order to correct the inaccurate reported ones [9].

Fig 1: A map view and a satellite view of Mina.

Fig 2: A map view and a satellite view of Jabal ar-Rahmah (ar-Rahmah Mountain) in Arafat.

Fig 3: A zoomed in satellite view of Mina showing location of *Maktab 40 Camp 32/204*.

Other research studies in the literature have been concerned with developing information-rich systems that can provide pilgrims with necessary information in order to effectively and adequately perform the Hajj and Umrah rituals. For example, Sulaiman et al. developed a question-and-answer expert system based on a knowledge base that is processed by an inference and search engine [10] Nevertheless, this research study is theoretical in nature and the authors merely propose installing the application on kiosks throughout the holy areas or on hand-held devices. The authors extended this system to help pilgrims make decisions in complex situations [11]. Mohamed et al. developed an Android mobile application, M-Umrah for the systematic guidance of the Malaysian Umrah pilgrims [12]. The author recently developed the mobile decision-support system, M-DSS based on both Case-Based Reasoning (CBR) and decision trees allowing users to provide questions of various complexity levels [13]. Zeki et al. developed a mobile Hajj dictionary in three different languages [14].

Other researchers considered personalized and context-aware recommendations. For example, Tayan et al. proposed a mobile learning system of Hajj and Umrah rituals for delivering information regarding how to perform a certain ritual to the pilgrim application depending on context such as the location, date and time [15]. A similar system exploits both historic and real-time context to provide location-based and time-based services [16]. Dynamic path recommendation based on shared geotagged social network data has also been proposed [17]. Ahmed et al. proposed intensive smart-city connections for efficient and smart delivery of relevant services [18].

From the above discussion, it is clear that the number and content of research studies concerned with Hajj and Umrah management are still far from being adequate. In other words, this is a promising area of research with many gaps to be filled. For example, local management of Hajj campaigns by corresponding managers is an open area of research that, to the best of our knowledge has not been touched yet. Accordingly, this paper presents a framework that allows both local (within campaigns) and global (across campaigns) Hajj and Umrah management as explained below.

IV. THE PROPOSED FRAMEWORK

Figure 4 depicts a block diagram of the proposed framework. As shown in the figure, this modular framework involves two types of cloud-based servers, one for the campaign (one for each campaign) and one for global management of the pilgrims by the Hajj and Umrah authorities. This is in addition to a pilgrim mobile application and a campaign manager mobile application. The goal of this modularity is to balance the services among several platforms for easier and more flexible management of the Holy events. In other words, it is impractical for the Hajj and Umrah authorities to be able to manage the whole events centrally. It is more practical to assign general services to them, and allow each campaign manager to handle the corresponding services ubiquitously via the manager application. The pilgrim application can handle some small-size static services.

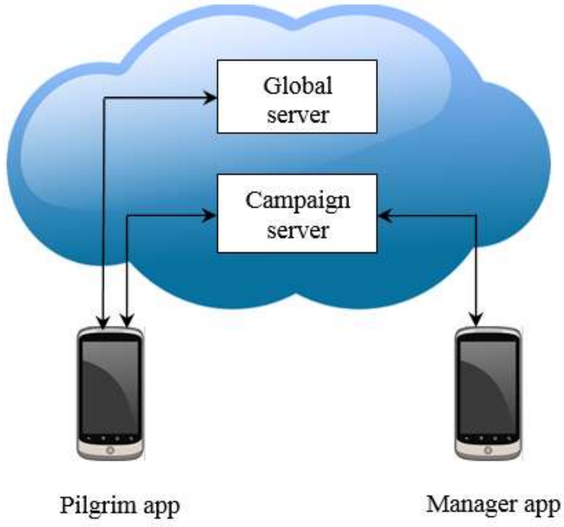

Fig 4: A block diagram of the proposed framework (images from pixabay.com).

It is worth noting that the cloud is an excellent choice for the management of huge amounts of data (Big Data) [19] and hence it is suitable for maintaining the information of the extremely large number of Hajj and Umrah pilgrims who visit the holy area simultaneously in addition to the information communicated to their mobile applications. Mobile-cloud computing refers to mobile applications that benefit from the cloud resources [20]. The proposed framework exploits this technology by saving large amounts of information on the cloud rather than on the pilgrim mobile to deliver them to the pilgrim or allow the pilgrim to access them upon request.

A. Pilgrim Application

There are several possible modes of communication between the pilgrim and the different modules of the proposed framework (pilgrim application, global server and campaign server) via the menus and icons provided in the pilgrim mobile application. The information language depends on the mobile locale. Those modes are as follows:

- Communication with the global server:
  - Request information
  - Send information
  - Receive information
- Communication with the campaign server:
  - Request campaign-specific information

- Send campaign-specific information
- Receive campaign-specific information

- Communication with the pilgrim application:
  - Request local and static information
  - Receive information

In the active mode, the pilgrim can request information. The pilgrim's request may be processed locally or by one of the servers according to the type of needed information. Local information include small-size hardcoded static information and context information extracted from the mobile sensors and hardware features. Some researchers developed context management frameworks to facilitate extracting both raw and high-level context values [21]. An example of a raw-context value is that of the GPS unit, while an example of a corresponding high-level context value is the interpretation of the GPS readings into the corresponding city or the corresponding street address. Examples of requests that the pilgrim forwards to the cloud-based global server are those regarding information on how to perform specific rituals. Such information is stored on the cloud to save the storage space on the mobile since it may include figures or videos or for the copyright protection of such media [22]. Some pilgrim requests require knowledge of the pilgrim context such as the prayer time or the weather forecast that require knowledge of the pilgrim's location. The mobile application extracts such context from the mobile sensors and forwards it to the server. In other words, the pilgrim application is context-aware. An example information that the pilgrim can alternatively request from the campaign server is dinnertime.

In the active mode, the pilgrim can also send information to either servers. An example information that the pilgrim can send to the global server is reports of emergencies. For example, when an accident happens, the pilgrim may send a short message accompanied by an image of the accident as needed. Images obtained using the mobile phone camera typically include embedded GPS coordinates that help authorities identify the incident location accurately. Alternatively, the pilgrim application can send such information automatically with the pilgrim message. An example information that the pilgrim can send to the campaign server is information regarding a local incident within the boundaries of the campaign residence. The pilgrim application allows the pilgrim to specify to which server it should send the information.

In the passive mode, on the other hand the pilgrim receives information from the local application or from one of the two servers. An example of local information is warning when the ambient temperature is dangerous for the pilgrim to be cautious. On the other hand, the global server can send warnings when a catastrophe happens in a specific location so that the pilgrim can avoid it. An example information that the campaign server can send to the pilgrim is a reminder of dinnertime. Similar to the active mode, the passive mode information, in many cases need to be also context-aware. For example, the server can send warnings regarding an accident in a specific location merely to the pilgrims in this location to reduce network traffic.

B. Campaign Manager Application

The purpose of the campaign manager application is to help each manager in configuring the corresponding cloud-based server even though those managers typically have no programming skills. In spite of the ultimate importance of such tools, they are relatively rare and so researchers should exert more effort in this direction. Configuring the campaign server refers to defining context-aware campaign-specific rules that would *fire* and send notifications and information to the campaign pilgrims' mobiles in specific contexts. Sending reminders to the campaign pilgrims' mobiles at dinnertime is an example of such rules.

To define the context of a rule, the manager is allowed to specify location, time (or time range) and date (or date range) at which the rule fires. The manager can also specify the pilgrim status, whether *inside* the location, *outside* the location, *arriving to* the location or *leaving* the location. The context also includes the type of pilgrim. As previously noted, there are three major Hajj plans and so the manager can classify them accordingly. On the other hand, to define the action of a rule, the manager can specify reminders that the campaign server can send and may allow the pilgrim to view specific image(s) or video(s). Two examples of such rules are as follows:

If (time = 7 A.M.) & (date = 07/12/1438 to date = 12/12/1438)
THEN *send a reminder "breakfast time"*

If (time = 1 A.M. to time = 3 A.M.) & (date = 07/12/1438 to date = 12/12/1438) & (location = campaign) & (status = arriving)
THEN *send a notification "please do not disturb"*

The system automatically applies a set of constraints on the developed rules before adding them to the rule base in order to help avoid errors. Examples of those constraints are as follows:

- A time range and a specific time cannot be specified simultaneously
- A date range and a specific date cannot be specified simultaneously
- A rule cannot be developed including a location combined with date range and/or time range without specifying the pilgrim status as entering or leaving (to avoid continuous firing)
- A rule cannot be specified for a pilgrim of type Ifraad regarding animal sacrifice
- Rules should not have contradicting simultaneous actions (in case of overlapping context specifications)

Fig 5: User defined (on the LHS) and system generated (on the RHS) location specifications.

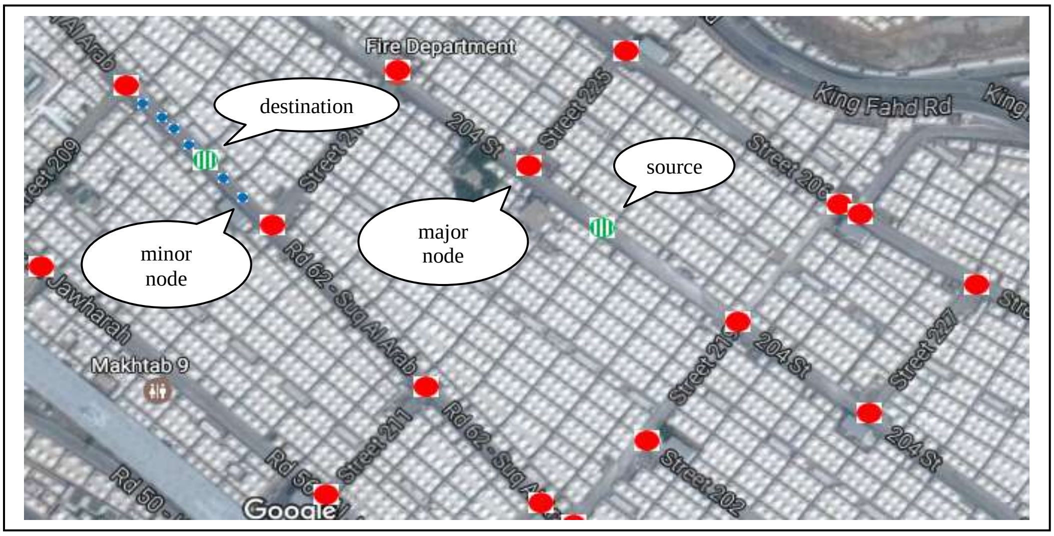

Fig 6: Visualization of the path computation algorithm.

It is worth noting that Martin et al. developed a similar system to serve tourists [23], but it was much simpler. It only allowed experts in the field to select a circular area on the map, a date range and a time range and a tourist status. Additionally, the system considered textual information (reminders) only. It is obvious that a circular area is impractical in most cases. For example, to cover Mina shown in Figure 1 using a circular area, we either have to include a considerable undesirable area or exclude a considerable required area. As explained in the following section, we consider several other methods of location identification.

As a final note, there is a need to develop similar rules for the global server in order to serve the global Hajj and Umrah pilgrims community, but professional programmers can develop them since we need only one set of rules for all pilgrims.

V. Location-based Services

Outdoors localization typically relies on the GPS system, while indoors localization typically depends on other technologies. This is because of the inaccuracy of the GPS readings (10 meters range). Technologies for indoors localization include iBeacons, infrared, Wi-Fi, Radio Frequency Identification (RFID) and Ultra-Wideband (UWD). The most accurate is the UWD [24]. Localization is required for three purposes in the proposed framework: to compare the pilgrim location with the locations specified in the context parts of the rules and to help compute paths to route the pilgrim upon request to the destination of choice or to answer location-based queries provided by the pilgrim.

A. Specifying Locations in Rules

The proposed framework allows the specification of locations in rules by several methods. Dropping a *pin* on Google Maps is the typical means of specifying a location. As previously noted, a major problem of Hajj and Umrah management is that of the unidentified locations on Google Maps, which implies that unless the manager knows the location visually or knows the GPS coordinates of the location, specifying it will be impossible. The Mina Locator mobile application [5] has partially addressed this problem. This application maintains the coordinate of the various campaign locations in Mina allowing their identification on Google Maps. In the proposed framework, the global server maintains a database of campaign locations (in Mina and Arafat) with corresponding GPS coordinates. The manager can select such a location from a provided menu and the system automatically maps the location to its GPS coordinates.

Nevertheless, in case of defining rules, it is more practical to specify an area rather than a specific location. Accordingly, we allow the specification of locations via a circular area or a polygon area on Google Maps. To facilitate this task, we allow users to specify the center and any circumference point of a circular area and the vertices of a polygon area and the system visualizes the areas as shown in Figure 5. Alternatively, pre-specified *famous* areas could be selected form a menu provided for this purpose.

It is worth noting that in case of rule development, the specification of the location in the context of each rule has to be compatible with the corresponding localization technology. Accordingly, in case of indoors localization, a location cannot be identified via its GPS coordinates due to the GPS inaccuracy and since local places (such as dining rooms and bedrooms) are, not only unidentified on Google Maps, but may not appear at all due to their relatively small areas. In this case, such locations have to be pre-specified in a menu and expressed in accordance to the localization technology used. The manger merely refers to the required place by its Id or alias. An example of such rules is as follows:

If (location = dining room)
  THEN *send a message "Bon Appetite"*

B. Specifying Locations for Routing Requests

In case of routing requests, the pilgrim specifies a location and the application computes the best path for routing to this destination. Researchers have established many algorithms over the years for the computation of the shortest path from a source to a destination. One of the most popular algorithms is Dijkstra's algorithm [25]. The complexity of this algorithm has been improved using Fibonacci heaps [26] and further using AF-heaps [27]. Speedup techniques have been proposed for improving its performance [28]. Quality-of-Service (QoS) routing is concerned with finding a path from the source to the destination such that it satisfies a set of conditions [29]. Dijkstra's algorithm has been extended for QoS routing [30]. The algorithm is used for routing on Google Maps and the corresponding APIs are used to visualize the computed paths [31].

In the proposed framework, the pilgrim may specify the required destination by dropping a pin on Google Maps or by providing the location name or address. To address the unidentified locations problem discussed above, the pilgrim can select a database location similar to the campaign manager. Whenever a pilgrim requests a path to one of those pre-specified locations, the destination is mapped to the corresponding coordinates so that routing can proceed, and can be visualized on Google Maps as in Mina Locator mobile application [5].

Within Mina and Arafat, routing can be performed based on database nodes. In this case, speed up techniques should be employed [28]. In our adapted approach, we divide the database nodes into major nodes and minor nodes. Major nodes include the source, the destination and nodes at intersections and dead ends. All the other locations are considered minor nodes. Routing is then performed based on major nodes. This requires maintaining information about major nodes in the database. This approach is visualized in Figure 6. Major nodes within the area of interest are identified by the large red circles. Minor nodes along one edge (between two nodes) are depicted using small blue circles. The source and destination are depicted using green dashed circles. Routing from the source to the destination is based on the red and green nodes only.

It is worth noting that indoors routing is performed similarly but with several differences. For example, the locations (such as bedrooms, restrooms and dining rooms) would be identified via any of the indoors technologies mentioned above. In addition, the database is maintained on the campaign server. Unfortunately, in this case, paths cannot be computed or visualized using Google Maps. Hence, a campaign-specific map and a corresponding routing algorithm have to be developed specifically for this purpose. We are working on this issue.

C. Other Location-based Services

In the proposed framework, we use the locations database for several other location-based services unachievable using Google Maps. These include:

- In case of detours due to emergencies, for example the locations database can be used to compute alternate routes, which are visualized on Google Maps.
- Paths computed based on the locations database can be enhanced via textual descriptions. For example, the following message may be generated:

  Keep moving until you find Maktab 40 Camp 32/204, and then turn right. You will pass by pharmacy "X" before you reach your destination

- The pilgrim can query the current location. In case it is within Mina or Arafat, the GPS coordinates of the pilgrim are mapped to the closest identified location in the locations database. The following message may be generated, for example:

  You are close to Maktab 40 Camp 32/204

VI. Evaluation

The goal of the evaluation was two-fold. First, we wanted to assess the usability of the campaign manager application even though such managers, typically have no programming skills. We also wanted to assess the degree of acceptance of the proposed framework and pilgrim application by past and potential pilgrims.

A. Prototype Implementation

We developed a prototype for the Android platform. The prototype included two cloud-based servers and two mobile applications, one for the pilgrims and one for the campaign managers.

Through the pilgrim application, the pilgrim could request information from any of the two servers. We prepared a menu of different rituals that the pilgrim could request from the global server, and specific virtual services that the pilgrim could request from the campaign server. The servers deliver textual information to the mobiles of the pilgrims upon request. Some descriptive images were prepared for some rituals. Pilgrims could also download those images upon request. This is in addition to location-based requests such as routing to a destination as explained in Section V. The servers could send notifications to the mobiles of the pilgrims in specific contexts. For the purpose of the evaluation, the global server sent reminders about next prayer time, in each pilgrim location, periodically (every fifteen minutes) in order to allow the pilgrims to get a sense of the application capabilities. Pilgrims could also send messages and notifications to either servers, possibly accompanied by relevant images.

Through a campaign manager application, the manager could develop rules for sending information to the pilgrims' mobiles based on context. The managers were allowed to define rules in which context could be specified in terms of any valid combination of the following: specific location, circular area or polygon area on Google Maps, a specific time, a time range, a specific date, a date range and pilgrim type in addition to the pilgrim status. Constraints such as mutual exclusion between a specific time and a time range were applied as previously noted. The action of each rule involved sending a notification in addition to possibly allowing the pilgrim to view an image.

B. Usability Test

To evaluate the campaign manager application, we adopted the criterion of Martin et al. [23], but adapted it to suit our framework. Ten managers with no programming skills tested the application. We allowed them to define rules using their applications and view the effect of firing those rules on other test mobile devices. In other words, for the purpose of the experiment, we allowed the rules developed by each manager to unconditionally fire and demonstrated the effect on a test mobile application, developed specifically for this purpose. After a short demo, we asked each participant to define five specific rules and recorded the corresponding times. All the participants were able to successfully define the rules with a noticeable decrease in time between the first two tasks and the following ones (as they gained more experience with using the application).

A System Usability Scale (SUS) questionnaire [32, 33] was prepared. This questionnaire proved to be successful in a multitude of usability tests over the years. We selected it, because its questions suited the assessment of the manager application. The questionnaire items are depicted in Table I. The participants provided scores to those questions on a Likert scale [34] between one (extremely disagree) and five (extremely agree). To compute the SUS score for each respondent, we subtract one from the score of each odd item in the questionnaire obtaining a number in the interval [0, 4]. We add the resulting five adjusted scores to obtain the odd SUS score, SUS_o, which is expressed as follows:

$$SUS_o = \sum_{i=1, i\ odd}^{9} (S_i - 1) \qquad (4)$$

Similarly, we subtract the score of each even item in the questionnaire from five and add the resulting five adjusted scores to obtain the even SUS score, SUS_e, which is expressed as follows:

$$SUS_e = \sum_{j=2, j\ even}^{10} (5 - S_j) \qquad (5)$$

Finally, we compute the SUS score of the questionnaire as follows:

$$SUS = (SUS_o + SUS_e) * 2.5 \qquad (6)$$

In other words, the SUS score is a number between 0 and 100. The computed scores ranged from 92.5 to 100 with an average of 97.25 indicating that the system is highly usable. We followed the SUS questionnaire by a single question regarding the reflection of the managers about the time needed to develop the rules. The average response was 4.7 indicating a very high degree of satisfaction.

TABLE I
RESULTS OF THE USABILITY QUESTIONNAIRE

#	Evaluation indicator	Average
1	Would use the system often	4.90
2	The system is unjustifiably complicated	1.10
3	The system is user-friendly	4.80
4	I cannot use the system without support	1.10
5	Functionalities in the system are integrated well	4.80
6	There are too many inconsistencies	1.10
7	Everybody can learn to use the system pretty fast	5.00
8	The system is very unwieldy to use	1.00
9	I feel self-assured when I use the system	5.00
10	I need to learn numerous things before using the system	1.30

C. *Satisfaction Questionnaire*

We prepared a satisfaction questionnaire for past and potential pilgrims. It included a number of questions intended to assess the satisfaction of the respondents with the framework and the pilgrim mobile application. Twenty respondents answered the questionnaire. By inspecting the results shown in Table II, it is clear that the respondents think the application is useful and easy to use. They also believe that it is highly conducive to facilitating the Hajj and Umrah rituals and improving their management. They would also readily use it. The internal consistency and reliability of this informal questionnaire results were assessed using *Cronbach's alpha*. We obtained a value of α equal to 0.89 indicating that the results are highly reliable.

TABLE II
RESULTS OF THE SATISFACTION QUESTIONNAIRE

Evaluation indicator	Average
Useful for Hajj and Umrah pilgrims	4.80
Conducive to improving Hajj and Umrah management	4.75
Conducive to facilitating Hajj and Umrah rituals	4.75
Would readily use it	4.90
Easy to use	4.70

VII. CONCLUSION

This paper proposed a modular framework for the management of Hajj and Umrah holy events. The idea is to distribute the different services rather than relying on the Hajj and Umrah authorities to manage the whole events. This is of ultimate importance since centralizing control of information and communication with such a large number of pilgrims is impractical and is a serious bottleneck. Accordingly, we proposed limiting the responsibilities of the Hajj and Umrah authorities to communicating general information that is independent of specific campaigns. On the other hand, each manager manages corresponding campaign-specific information. To the best of our knowledge, this research study is the first to consider Hajj and Umrah campaign management. On the other hand, services depending on context extracted from the on-board mobile sensors and hardware features in addition to small size static data are delegated to the pilgrim mobile application itself. The system provides important location-based services, which are unachievable using Google Maps.

The campaign manager application allows each manager to ubiquitously and conveniently manage the corresponding campaign and develop rules to control communicated information to the corresponding pilgrim applications according to context without requiring programming skills. It automatically applies constraints on the developed rules to help avoid errors.

We developed a prototype based on the proposed framework and the results of the empirical evaluation showed the satisfaction of past and potential pilgrims with the promising capabilities of their application. The evaluation has also shown the usability of the campaign manager application. We are currently working on developing a full system rather than merely a prototype to apply it in the upcoming Hajj event. We are mainly concerned with the campaign server and its communication with both mobile applications since it is more challenging in comparison to the global server. We also intend to consider practical low-cost indoors localization and routing within campaign residences.

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