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Adaptive routing strategy for emergency applications in smart campus

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ABSTRACT

Smart campuses consider that building and people are the holders of the sensor nodes. These nodes can be stationary or mobile, the former are attached to buildings, while the latter are carried by people and move as they go such as smartphones, smart watches, tablets, etc. These components are considered a hybrid network that includes static and dynamic nodes that are connected with each other. The smart applications that can use this kind of networks vary from the emergency, advertising, to announcements applications. Practically, implementing alternative networks in smart campuses poses challenges due to the limited capabilities of hardware, software, and connectivity of nodes. One of the major issues is the unpredictable consumption of resources in such networks, particularly in emergency and disaster situations where traditional Internet connectivity may not be available. This work suggests approaches that can be adopted in the applications of smart campuses. To this end, real-world situations are simulated aiming at testing the proposed approaches. Several routing protocols are involved and benchmarked. The assessment of the protocols is based on three metrics; messages spreading, places covered, and the number of nodes that received messages. The results show that the better selection of the routing protocols for smart campuses is based on the application required in campus. Therefore, this work suggests what is termed message-specific efficient message-oriented routing (EMOR) as approach for alternative network applications in smart campuses where the selection of the routing protocol should be adaptively changed over time as needed (e.g., emergency, announcements, advertising, etc.).

Keywords: Hybrid Networks, Information Dissemination, Routing Protocols, Smart Campus.

1. INTRODUCTION

1.1 Overview

Smart campus concept is one of the sophisticated terms that has been recently introduced in the literature (Dong et al., 2020). The implementation of smart campus requires many devices connected (e.g., sensors, smart devices, servers, etc.) to the Internet, communication system, and data analytics (Abuarqoub et al., 2017). These components are used to provide services in campus and manage the operations in a way that saves time, campus resources and people safety (Min-Allah and Alrashed, 2020). One of the most important services that is provided by smart campuses is the safety of students, staff, and faculties. In emergency situations (e.g., disasters), smart campus plays a significant role in mitigating the challenges that people may face. Therefore, emergency preparedness is crucial area of research that should be given a special attention researchers, developers, and network architects. Smart campuses should provide an effective communication system, a detailed action plan for mitigating damages and saving lives (Polin et al., 2023).

Furthermore, in smart campuses, it is more likely that every person has Mobile Ad Hoc Network (MANET) network access. In this regard, smartphones, which are mobile nodes, are commonly considered to be efficient for alerting in emergency and security threats (Mahmood, 2021; Laghari et al., 2023a; Mowbray et al., 2023). In practice, the signal strength of mobile phones varies within different areas and has a limited range, resulting in unreliable communication (Babatunde et al., 2024). Therefore, efficient routing protocols are crucial for the purpose of emergency situations. Moreover, during an emergency, excessive mobile phone use by students, faculty, and security staff can cause mobile phone networks to overload and shutdown (Bean and Nels, 2023; Gowda et al., 2023). Natural disasters such as hurricanes, storms, earthquakes, and cyber-attacks can also disrupt major networks. As part of many university emergency plans, mobile phone communication is used as a backup to the usual communication network, making this an extremely critical issue (Stute et al., 2020; Nasir et al., 2022). Smart campuses should have the ability to handle critical situations such as evacuations, security threats, severe weather, fires, hazardous material releases, tornadoes, flash floods, terrorist threats, etc. MANET networks enable emergency responders in securing critical "up-to-the-second" emergency alerts to the people in campus during chaotic events where evacuation may not always be the best option (Jiang and Yin, 2023; Krishnakumar and Asokan, 2023; Soomro et al., 2023; Madhavrao and Rao, 2024).

In ad hoc networks, spreading data messages from one node to all network's nodes can be performed for the purpose of distributing information simultaneously to multiple recipients (Mahmood et al., 2015; Gao et al., 2023; Laghari et al., 2023b). However, this kind of information spreading reveals considerable challenges in emergency situations such as the following:

- Limitation in resources: In campus emergency situations, there may be a shortage of available network resources due to damage or power shortage, which leads to have unreliable network infrastructure (Pasetti et al., 2020; Gao et al., 2024; Laghari et al., 2024).
- Heavy traffic: In emergencies, people in campus try to contact emergency services, friends, and family, or share critical information in an unpredicted pattern. As network traffic increases, broadcasts are delayed and can become congested (Sivanathan et al., 2017).
- Topology issues: During emergencies, network topology may change due to many reasons such as infrastructure damage, power shortage, and the mobility of affected users. This situation leads to have many challenges in establishing and sustaining effective broadcasting routes (Alramli et al., 2020; Liu and Wang, 2023).
- Signal attenuation and interference: During disasters, the strength and quality of the signal are highly affected and become unstable. It leads limit the broadcasting of data messages, decrease network coverage, and errors in transmissions (Minoli, 2017).
- Localization: In emergency situations, data messages should be transmitted to particular targets within the network (e.g., medical staff, victims, or rescue teams) (Basnayake et al., 2023).
- Power constraints: Mobile devices are usually used for emergency communication, but they are limited in battery life time. Therefore, minimizing the consumption of power in these devices is crucial, which is a challenge (Blazevic and Riehle, 2023).

1.2 Literature Review

The literature includes many studies that consider smart campus resources consumption and management. Most of the studies try to propose approaches that minimize the consumption of smart campus network resources such as energy and other resources. Other studies suggested strategies for improving the performance of the communications system of the smart campus in case of disasters and emergency situations. The study of Wang et al. (2019) suggested a multi-source data monitoring system for earthquakes emergency response for in campus. Their case study was applied in Shahe campus in the Central University of Finance and Economics/China. The goal of their system was to provide timely and effective emergency response strategies. These strategies were based on factors related to buildings damage and occupancy, hazardous chemicals, and other important factors. Their proposed system showed its efficiency in resources consumption (e.g., energy) as well as it showed fast response to the emergency situations. The main issue in the study is that it needs to be verified in terms of the consumption of other network resources. Another study performed by Abukhalaf and Von Meding, (2020) studied the issues of in campus planning in emergency situations. Their study was focused on a specific case in the University of Florida during Dorian hurricane. The investigation performed by this work detected many challenges in the communication system of the university campus; the appropriateness of communication platforms used, misleading information, customized communications, timing and orientation sessions, and language obstacles. The study found that these challenges can be mitigated for better disaster risk management and for obtaining better in-campus development strategies. A postgraduate thesis (Brewer, 2021) performed a comprehensive study to explore the main strategies that are adopted by higher education institutions in emergency situations. The author investigated the implementation of emergency notification systems (ENS) and how they could be utilized in supporting communication systems in risks and emergency situations. The study showed that stakeholder satisfaction, structured change processes, and the standards followed in ENS systems are crucial to be verified. However, the drawback of the thesis was in dealing with heterogeneous systems, which limits the ability of the systems to have real-time responses.

Moreover, the research of Barroso et al. (2023) described the cyber-physical system of future smart campus based on IoT infrastructure and SmartPoliTech. They developed different kinds of services such as alerting systems, data visualization, and consumption modeling. Their proposed framework has the ability to control all the software and hardware processes in the campus. Their framework is also used to predict the water consumption in an hourly, daily, weekly, or monthly basis. However, the system may struggle traffic load, which needs high specs hardware. The work of Henrique et al. (2023) considered a Brazilian university as a smart campus aiming to minimize the loss in electric by adjusting photovoltaic systems and charge stations in campus. The work showed that their proposed approach reduced the consumption of resources in campus. In the same year, Roda-Sanchez et al. (2023) proposed an approach called digital twin for Espinardo university campus. They used cloud computing techniques and the sensor network of the campus to generate highly detailed digital replicas of physical objects and the semantic information of them. The collected information and knowledge were used to generate models for predicting the consumption of resources such as the energy. They found that their proposed approach contributes to improve the life in campus. On the other hand, the limitation of the study was in the accuracy of prediction when having a real-life situation under difficult environment circumstances. A recent study by Anggoro et al. (2024) suggested a solution that adapted green culture for smart campus aiming to improve the environmental performance of the staff. Their proposed approach was based on a structural model that used data from surveys and questionnaires. The results showed that the academic leaders at various levels require more featured abilities that perform more progress toward smart campus. The problem in the study was on the responses of the surveys and questionnaires that might not be comprehensive and biased. Another work performed by Apiratwarakul et al. (2024) to compare the response time when using traditional and smart campus services in university campuses. The study showed that smart campus was significantly faster in response during emergency situations. However, this finding may vary from one campus to another depending on the infrastructure.

1.3 Problem Statement and Contribution

According to the literature, there is a lack in studies that consider providing detailed information about smart campus design in emergency or similar situations. Most of the studies investigate the implementation issues of the routing protocols and movement patterns of nodes. Hence, the contributions of this work are as follows:

- This work involves examples of real-world scenarios where smart campus design strategies can be applied to investigate the appropriateness of routing protocols for emergency applications.
- Simulating MANET scenarios that imitate emergency situations in a university. The proposed approach is termed efficient message-oriented routing (EMOR) for alternative network applications in smart campuses where the selection of the routing protocol should be adaptively changed as needed based on the situation or the service needed (e.g., emergency, announcements, advertising, etc.).

The rest of this document is organized as follows: Next section illustrates the research method in terms of the experiments design and the settings adjusted. Section 3 demonstrates the obtained results and discussions. Section 4 concludes the work and shows the limitations as well as the future works.

2. RESEARCH METHOD

2.1 Simulation Environment

The environment considered in this study is part of the University of Mosul (UoM) Campus. This part includes 30 buildings that are distributed over an area of 1 squared kilometer. Table 1 presents the names of these buildings, number of floors of each building, the number of static sensors inside each building, and the number of people (students, faculties, and staff) who use each building. Moreover, Fig. 1 depicts the actual positions of the buildings of this study on the map. Each building has specific number of stationary sensors (e.g., fire detectors, smoke detectors, temperature sensors, humidity sensors, etc.) that are attached to the building based on the UoM policies. The number of people who use the building is obtained from the university officials for the sake of this study. The number of mobile sensors of each building represents the number of people who use the building. This is inspired by the assumption that each individual in the building holds a smartphone that include a variety of sensors and use the UoM smart campus application that is authorized to access some information inside the campus. Also, all the mobile sensors can move freely within the campus since individuals can go outside the building and back later.

2.2 Description of Smart Campus Scenarios

The scenarios that are needed by the UoM smart campus (UoM-SC) vary and depend on the applications that the university officials want to adopt. The following are examples of the most frequent scenarios:

- Emergency situations: It occurs in case of emergency when having a problem in the campus and the campus security want to inform some of the people to stay or to leave their building, or to avoid some building. It is important to mention that the main network infrastructure is down, and the campus may be operating on a MANET alternative backup plan.

Table 1. UoM building that are considered in this study alongside their floors and the number of static and dynamic sensors

#	Buildings	# of floor	# of static sensors	# of mobile sensors
1	Computer Engineering Dept.	3	15	208
2	College of Science Deanship	3	15	166
3	Civil Engineering Dept.	3	15	39
4	Mechatronics Engineering Dept.	2	10	45
5	Biology Dept.	5	25	51
6	Chemistry Dept.	3	15	220
7	Renewable Energy Dept.	4	20	102
8	Computer Center	2	10	67
9	Water Resources Engineering Dept	2	10	195
10	Mechanic Engineering Dept.	2	10	70
11	Geology Dept.	2	10	67
12	Physics Dept.	2	10	46
13	College of Computer Science and Mathematics Deanship	3	15	340
14	Statistics and Informatics Dept.	2	10	107
15	College of Engineering Deanship	4	20	358
16	University Theater	1	5	17
17	Central Library	4	20	116
18	Students Housing	2	10	100
19	Student Affairs	2	10	93
20	University Bank	1	5	9
21	College of Pure Sciences Education Deanship	6	30	268
22	Computer Science Dept.	3	15	100
23	Software Dept.	3	15	350
24	Sports Science Dept.	2	10	100
25	College of Art Deanship	4	20	764
26	Geographic Dept.	2	10	43
27	Islamic Edcation. Dept.	2	10	72
28	Computer Education Dept.	3	15	43
29	Mathematics Education Dept.	3	15	56
30	Agricultural Mechanics Dept.	1	5	7
	Total		405	4219

- Announcements: It happens when it is needed to inform the people of a building (e.g., department) about a particular information. A smart campus can implement social announcements that are directed to groups of people who are located in different areas within the campus. This allows for targeted and efficient communication based on specific locations and relevant groups.
- Advertising: In case of the university want to advertise its events to students, faculties, or staff, it is needed to forward messages to some people base on various criteria such as location, college affiliation, position, and importance.
- Traffic flow: In big campuses, the traffic of people including their vehicles should be directed in rush hours. This can be performed by broadcasting messages to direct people to, for instance, exit the campus using particular campus gates aiming at avoiding bottle neck situation at some gates. In fact, combining emergency actions with the complexity of targeted messaging based on various criteria adds an additional layer of complexity to the smart campus. In scenarios where certain areas are of potential dangerous and should be avoided, the scenario of the authors' interest is the emergency.

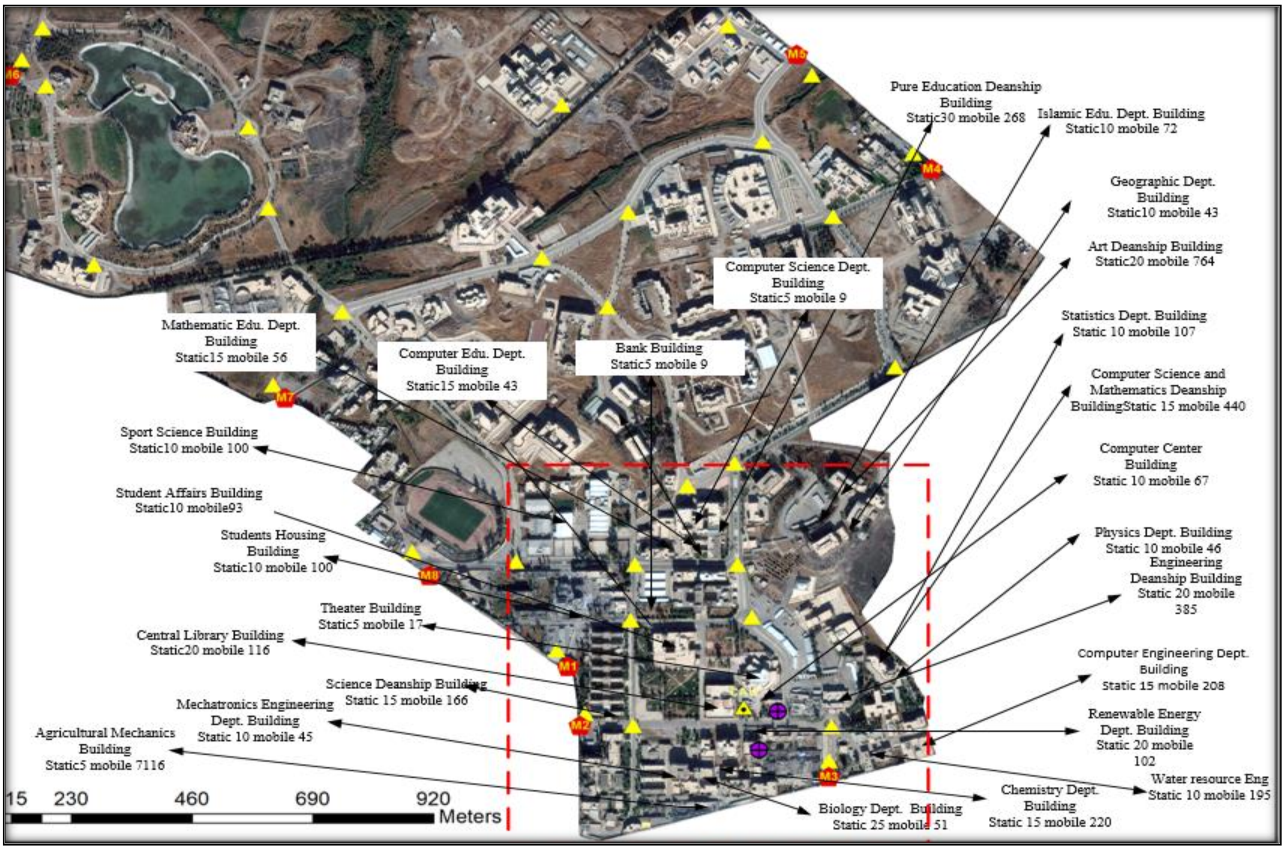


Fig. 1. University of Mosul campus, the squared dotted area represents the area of study. The figure also shows the buildings on the study area

2.3 Experiments Components

The design of the experiments in this work includes many components and described as follows:

- Routing protocols: Three main routing protocols used in this work are:
  - Broadcasting: This kind of routing broadcast data messages to all nodes that are in same communication range of the message holder. It mainly used to benchmark its results with other routing protocols (Shah and Kasbe, 2021). However, even though this protocol consumes a lot of resources and energy but it is involved in this work for two purposes; first, to benchmark the other two protocols in used this work and to show the appropriateness of this protocols when it shows advantages more than weak points.
  - Probabilistic flooding: This protocol is used in ad hoc networks for distributing data to nodes. In contrast with the previous protocol, a node sends data to another node based on a predefined probability aiming to minimize the overhead and congestion in the network, which in turn, consume network resources (Lindgren et al., 2004).
  - Spray & wait: This protocol is also used in ad hoc networks based on a particular strategy. This strategy has two phases, the spray phase sends messages to a fixed number of nodes that are randomly selected, while the wait phase means that a node holds messages until it encounters the destination. The two phases are repeated and restricted by a predefined time (Spyropoulos et al., 2005).
- Movement patterns: The movement pattern used in this work is called Levy Flight (Tomasini et al., 2017). However, this model followed a pattern that makes nodes cross the boarders of the environment. Therefore, this model is modified by restricting nodes to move inside the environment, hence, the model is called Levy Flight with Exponential Cutoff. This study suggests that this pattern reflects the movement of staff and students within the university campus.
- Evaluation metrics: Three metrics are used to assess the performance of the experiments of this work. First, fraction of places within the environment that are covered by the communication range of the dynamic nodes. Second, the number of data messages spread to the nodes within the simulation environment. Third, the fraction of acknowledged nodes by the data messages (number of nodes received messages). These metrics provide insights into the network's performance, message delivery effectiveness, and resource impact on nodes.
- Communication: The nodes within the UoM-SC use Wi-Fi technology for static and dynamic nodes. In this work,

50 meter is used as the communication range of all nodes. The study proposes the implementation of a free-noise Wi-Fi environment and MANET communication in a free space.

- Nodes Deployments: The deployment of the nodes in the UoM-SC is based on Gaussian approach. This kind of deployment reflects a real situation that is based on the distribution of the buildings in campus inside UoM-SC as shown in Fig. 1. In addition, the distribution of people in the campus also followed the same strategy. In Gaussian distribution, nodes are not focused in a particular place in UoM-SC, instead, they are deployed in particular places that are approximately follow a Gaussian distribution in nature (Attard et al., 2023).

2.4 Experiments Features

The simulation environment is designed to imitate the UoM-SC in terms of the dimensions and the other features. Table 2 and 3 describes the details of the simulations' main settings and parameters. It should be mentioned that this work includes three main simulations, each of which is rum for 30 times. The programming language used to perform the simulations is Netlogo. The concept of parallel processing is enabled when running the simulations in a way that the load is distributed to all the CPU cores of workstations aiming to obtain rapid runs. The output of the experiments is stored in .csv file.

Table 2. Details of experiments settings for simulating UoM campus

Item	Value
# of static nodes	405
# of dynamic nodes	4219
Static nodes communication range	Wi-Fi (50 m)
Dynamic nodes communication range	Wi-Fi (50 m)
Static nodes deployment strategy	Lattice deployment
Dynamic nodes deployment strategy	Normal (Gaussian) deployment
Warning/advertising/notification source	Random
Routing protocols	Broadcasting, spray & wait, probabilistic flooding
Movements pattern of dynamic nodes	Levy flight with exponential cutoff
Number of runs for each experiment	30

Table 3. Experiments parameters adjustments

Parameter	Value	Description
δ	0.5	Probabilistic flooding adjustment
α	1.55	Levy flight movement patterns adjustment
Cutoff length	10	Levy flight movement patterns adjustment
Cutoff time	850	Levy flight movement patterns adjustment
Back time	100	Levy flight movement patterns adjustment

3. RESULTS AND PERFORMANCE EVALUATION

As mentioned in the previous section, three main experiments were designed based on the scenarios considered. The performance of each experiment in this work represents the average of 30 runs because each run provides a result that might be different from the other runs due to the existence of dynamic nodes that can be deployed differently in each run. Therefore, averaging the 30 runs almost reflect the actual behavior of the experiments.

Table 4 presents a summary of the experiments performed in this study. The table shows the performance of the three metrics using four indicators of all the experiments, namely; minimum value, maximum value, average maximum steps that is required to finish the experiments, average time (in minutes) that is required to finish the experiments. As can be seen, the minimum number of messages in all the experiments was 0, which is reasonable since no messages were exchanged at the first steps of all the experiments. The highest number messages in all the experiments is 3712.22581 using Broadcast routing protocol, while the lowest is 565.291667 by Spray & Wait routing protocol. Moreover, the highest fraction of places covered in the UoM-SC is obtained using the Broadcast routing, while the lowest obtained using Spray & Wait routing. Moreover, the highest fraction of acknowledged nodes obtained by Spray & Wait routing, while the lowest obtained by Broadcast routing. Finally, the time consumed by Spray & Wait routing is higher than the other routing protocols, while the Broadcast consumed lower time.

Practically, the Broadcast routing is usually used for benchmarking purposes, but in specific situations it can be adopted in emergency events. However, it significantly consumes power and memory, therefore, it can only be used in very specific situations (e.g., advertising messages that should be forwarded to all individuals within an environment even with redundancy). For immediate action and coordination, the smart campus system implements a backup MANET network. A broadcast message can provide evacuation routes, information about safe zones and exits, or instructions for specific groups of people based on their roles or responsibilities, like security and firefighters. Using Spray & Wait routing, lowering number of messages refers to utilizing Wi-Fi channels as efficiently as possible to optimize the node's power consumption and memory buffer, as well as reducing noise and interference on the network overall, but it significantly consumes time. This might be useful in the applications that do not have concern about time. For example, sending announcements to the security team about their rules next weeks as an action for long-term emergency situations such as earthquake. In contrast, the performance of the Probabilistic flooding is useful when it is needed to forward announcements in a short period of time. For example, forwarding instructions to the people inside the UoM-SC when needed to direct them to particular exist gates and avoid bottle neck situations. However, the power and memory consumption is also considered high compared to Spray & Wait routing.

According to the aforementioned description, each routing protocol is useful in particular situations. For example, some situations may be critical in terms of time, resources, or maximum coverage. Therefore, it is suggested to use adaptive hybrid approaches (In this paper, each message employs its own type of routing communication, referred to as EMOR, which is dynamic and can be adopted as the routing strategy in UoM-SC. In other words, the selection of the routing protocols should be determined according to the application involved at particular time and each application produced its own EMOR messages. This means the design of the network is dynamic and governed by the application involved.

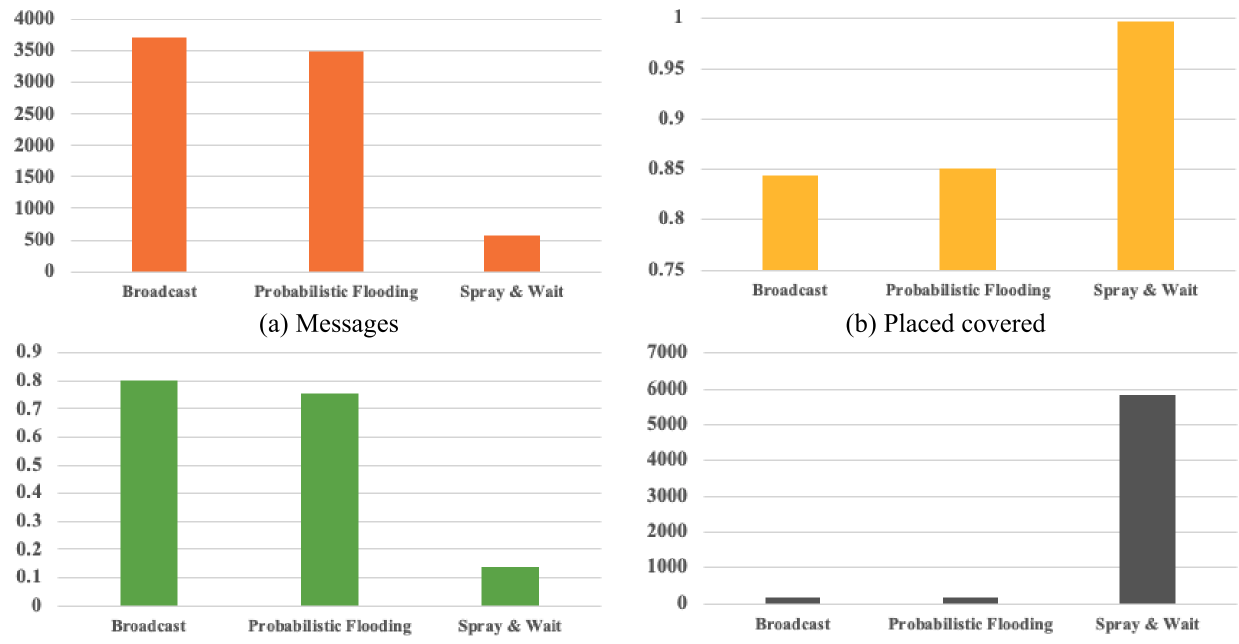
Now, the results should be investigated with more detailed analysis aiming to verify the description mentioned in the previous paragraph (Yin et al., 2024a). Fig. 2 (a, b, c, and d) depicts the benchmarking of the three routing protocols; Broadcast, Probabilistic flooding, and Spray & Wait in terms of average maximum messages consumption, average maximum places covered the communication range, average maximum percentages of nodes received messages, and the average maximum time required to finish the simulations respectively. In Fig. 2(a), the number of messages is significantly minimized when using Spray & Wait compared to the other two routing protocols. Fig. 2(b) shows that the places covered with communications is obtained when using Spray & Wait. Fig. 2(c) demonstrated that the number of nodes that receive data messages is relatively high when using Broadcast and Probabilistic flooding compared to Spray & Wait. Finally, Spray & Wait consumes longer time than the other two routing protocols.

Table 4. Descriptive statistics of the results that represent the average of 30 run of the experiments.

Indicator	Messages consumption	Fraction of places covered	Fraction of nodes acknowledged
Broadcast routing protocol			
Minimum value	0	0	0
Maximum value	3712.22581	0.80318745	0.8430293
Average simulation steps	136.903226	136.903226	136.903226
Average time (min)	164.28	164.28	164.28
Probabilistic routing protocol			
Minimum value	0	0	0
Maximum value	3487.74194	0.75487358	0.85127328
Average simulation steps	149.870968	149.870968	149.870968
Average time (min)	179.844	179.844	179.844
Spray & Wait routing protocol			
Minimum value	0	0	0
Maximum value	565.291667	0.13591892	0.99660572
Average simulation steps	4864.95833	4864.95833	4864.95833
Average time (min)	5837.949	5837.949	5837.949

Furthermore, the obtained results should be assessed in terms of the performance variations of the three routing protocols in terms of the three metrics used. This step is important to show the stability of the 30 runs of each protocol. In the Broadcast routing protocol, the fraction of covered places in UoM-SC using Broadcast routing protocol for 30 runs is depicted in Fig. 3.

The figure illustrates a range of workspace, enabling the prediction of performance (Yin et al., 2024b), particularly in terms of coverage area. This aspect highlights a key point regarding reliability in various solutions and applications. As can be observed in the figure, all the runs have outliers that is the side effect of the movement pattern used in the experiments. Therefore, it is crucial to emphasize that in the design of smart campus, the phase-one design should incorporate basic network protocols and consider the patterns of people's movement. This study, specifically relies on the Levy movement pattern, which closely resembles the actual movement patterns observed within the university campus at various times and applications. The measurement of the covered places in the UoM-SC is highly governed by the movement of nodes that follow Levy Flight with exponential cutoff reflecting human movement patterns. Fig. 4 shows the variations of the runs in terms of the number of data messages. It is clear that the performance is almost stable with delay at the first quartile of each run. This is reasonable due to two reasons; 1) the first node that receives a message may be far from the other nodes and take time to join the other nodes and interact with them. 2) all the simulations take time to start spreading data messages especially when a message is broadcasted but no nodes are close enough to receive the message.



(a) Messages (b) Placed covered

(c) Acknowledged nodes (d) Time required (min)

Fig. 2. Benchmarking the routing protocols used in terms of four indicators: (a) Messages consumption, (b) Places in UoM-SC campus covered, (c) People received messages, (d) Time (min) to finish the simulations

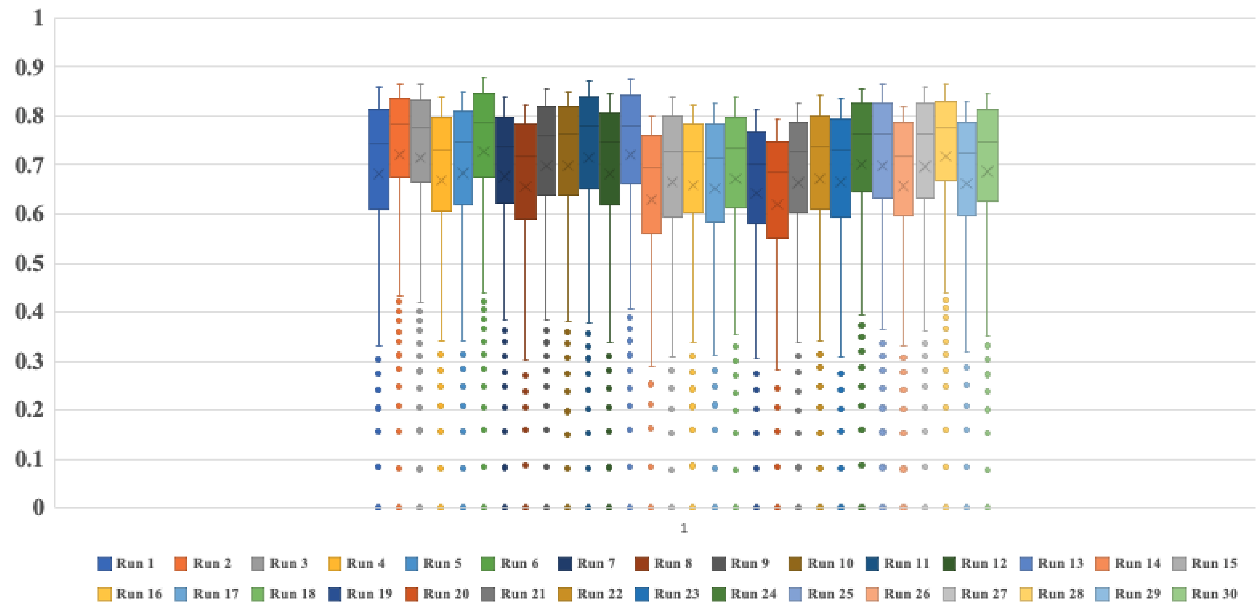


Fig. 3. Boxplot of the fraction of covered places in UoM-SC using Broadcast routing protocol for 30 runs

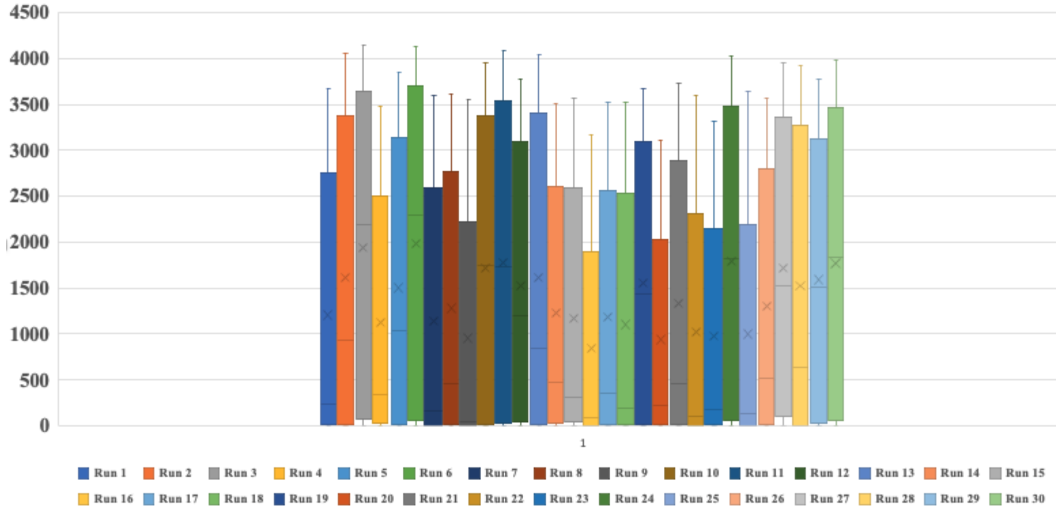


Fig. 4. Boxplot of the number of messages in UoM-SC using Broadcast routing protocol for 30 runs

Similar behavior is observed when exploring the variations of the fraction of acknowledged nodes in UoM-SC as shown in Fig. 5. Fraction of acknowledged nodes and their response to an event implies, from a broader perspective, that the message reaches a larger portion of people in announcement or emergency applications. Conversely, sharing also entails a potential burden on the alternative network and the consumption of critical node resources. While fraction of acknowledged nodes can enhance the reach and effectiveness of message dissemination, it is important to consider the potential impact on the backup alternative network. Active communication node increases channel utilization of the network, potentially leading to congestion and decreased performance. Additionally, critical node resources may be consumed at a higher rate due to the increased message traffic, potentially affecting the overall system's reliability and response time.

In the Probabilistic Flooding routing protocol, Fig. 6 demonstrates a boxplot of the variations for 30 runs of the fraction of the covered places in the UoM-SC. As mentioned, this is the impact of the movement patterns of the nodes. Fig. 7 depicts the variations of the protocols when spreading data messages. It can be observed that outliers appear in Run 4 and Run 20, which reflect unstable behavior of these two runs. This means that this protocol is always stable due to these outliers. The reason behind the unstable behavior of the two runs is the dynamic nature of the network where many nodes are distributed in random areas within the UoM-SC. However, this situation is not frequently happened since most of the runs show stable behavior.

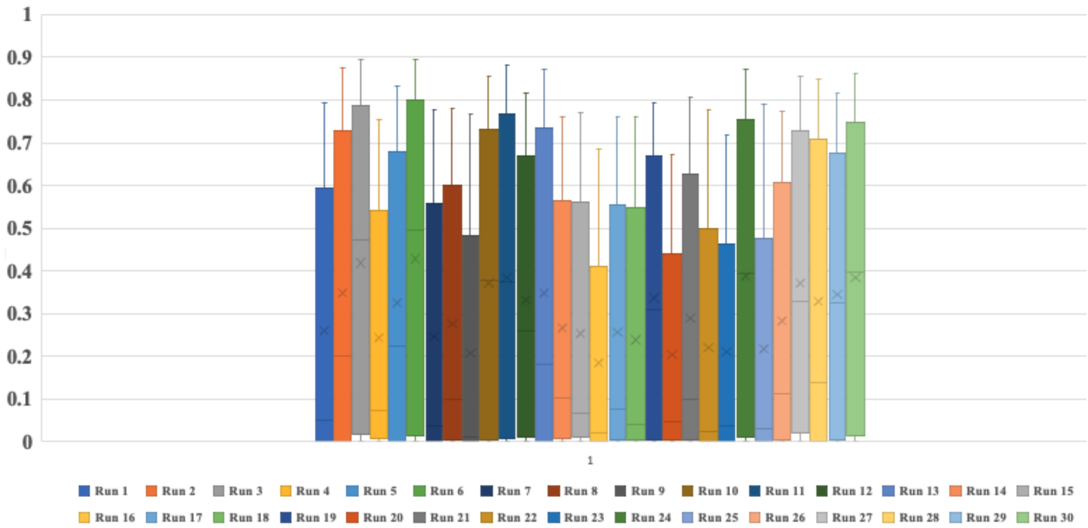


Fig. 5. Boxplot of the fraction of acknowledged nodes in UoM-SC using Broadcast routing protocol for 30 runs

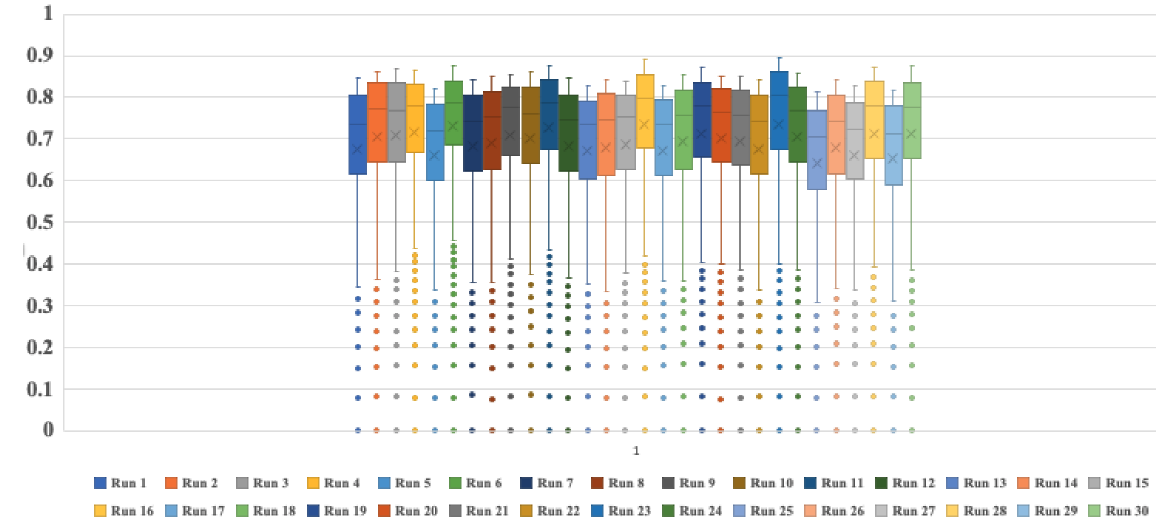


Fig. 6. Boxplot of the fraction of covered places in UoM-SC using Probabilistic Flooding routing protocol for 30 runs

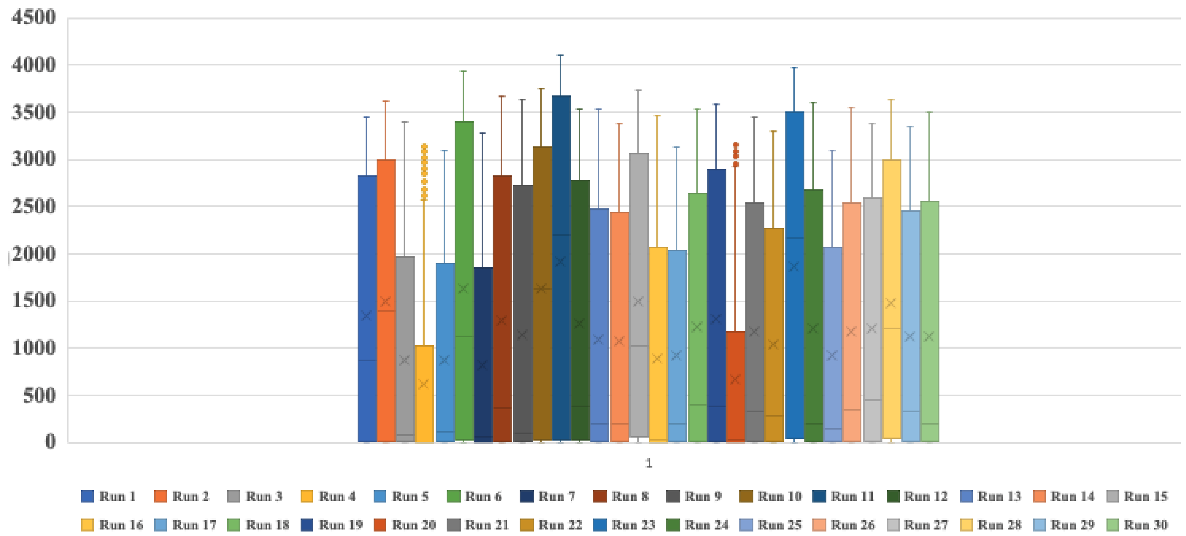


Fig. 7. Boxplot of the number of messages in UoM-SC using Probabilistic Flooding routing protocol for 30 runs

Fig. 8 shows almost a stable behavior when observing the fraction of the acknowledged nodes in UoM-SC. Instability can practically be a weakness point in certain applications that demand consistent performance and prior preparation. However, from other perspective, it offers the advantage of providing predictability into the number of participating nodes in the response. This enables a preliminary estimation of the message transmission burden on the network and the consumption of communication channels. The knowledge of the number of nodes involved in the response brings valuable insights from a technical standpoint. It allows for a better understanding of the potential impact on the alternative network, such as increased traffic and channel utilization. This information supports in evaluating the scalability and capacity planning required to accommodate the anticipated load. While instability poses a challenge in terms of performance predictability, the ability to understand the level of participation node in specific application can help in making informed decisions regarding network resources and optimizing communication channels. By considering this factor during the design and implementation stages, it becomes possible to adapt and allocate resources efficiently, mitigating the negative effects of instability while ensuring effective message transmission and network performance.

In the Spray & Wait, a similar behavior of the variations of the fraction of covered places in UoM-SC is shown (see Fig. 9). Fig. 10 depicts that the nature of the routing protocol plays a significant role in obtaining relatively different number of messages of the runs such as Run 1 and Run 16 that show lower number of data messages. This is, in fact, a normal situation considering the algorithm of the Spray & Wait routing protocol. Fig.11 demonstrates the variations of the 30 runs in terms of the fraction of covered places in UoM-SC. It clear that the behavior is almost the same compared to Fig. 10, which reflect the stable behavior of this routing protocol.

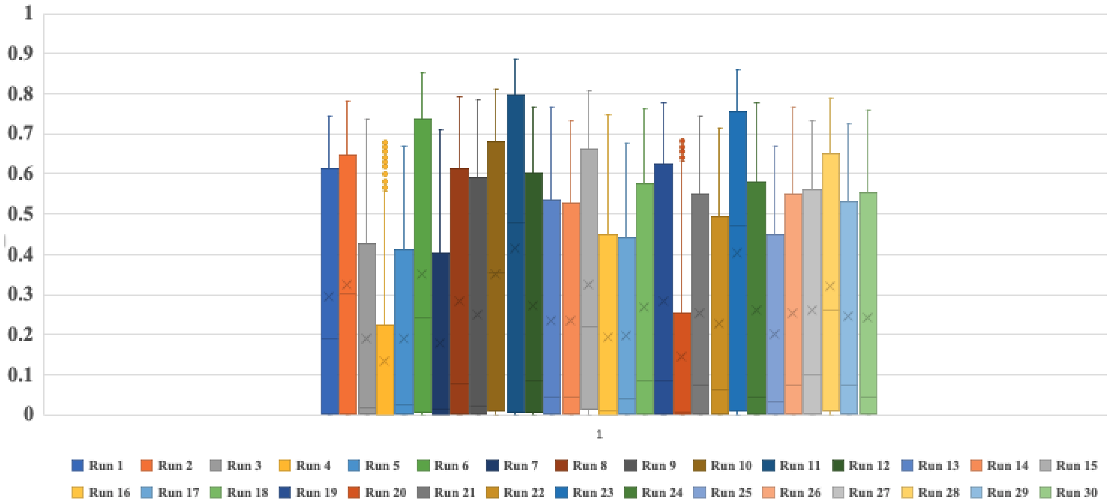


Fig. 8. Boxplot of the fraction of acknowledged nodes in UoM-SC using Probabilistic Flooding routing protocol for 30 runs

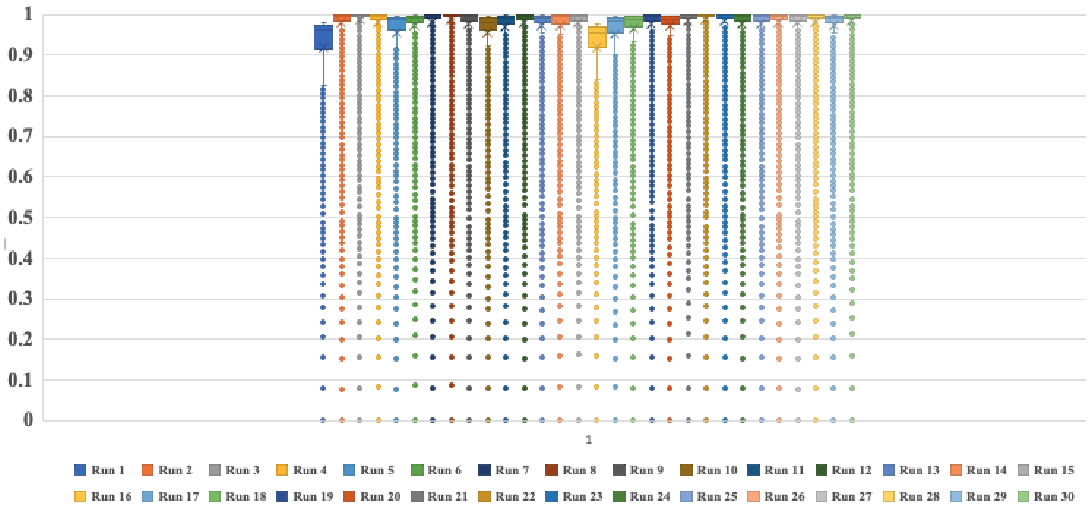


Fig. 9. Boxplot of the fraction of covered places in UoM-SC using Spray & Wait routing protocol for 30 runs

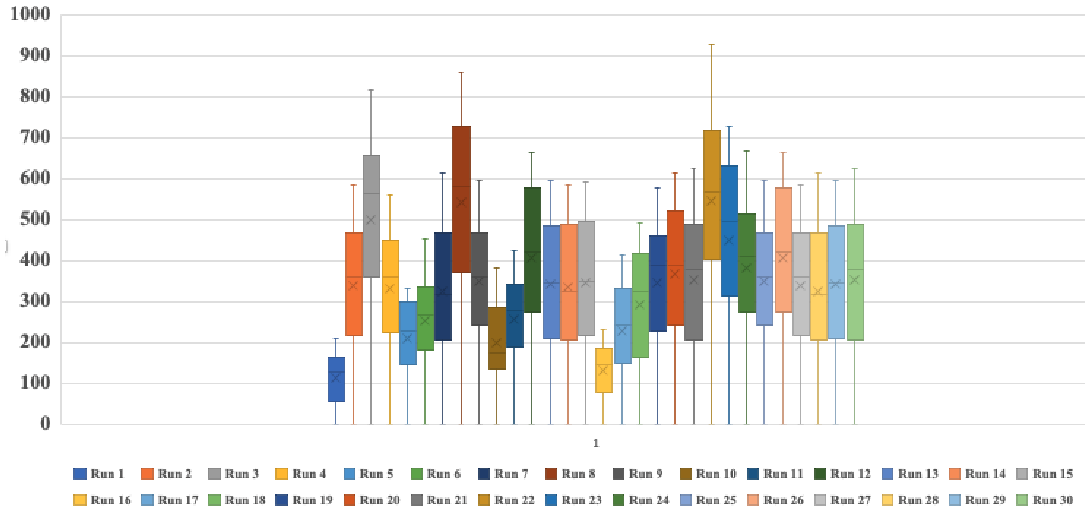


Fig. 10. Boxplot of the number of messages in UoM-SC using Spray & Wait routing protocol for 30 runs

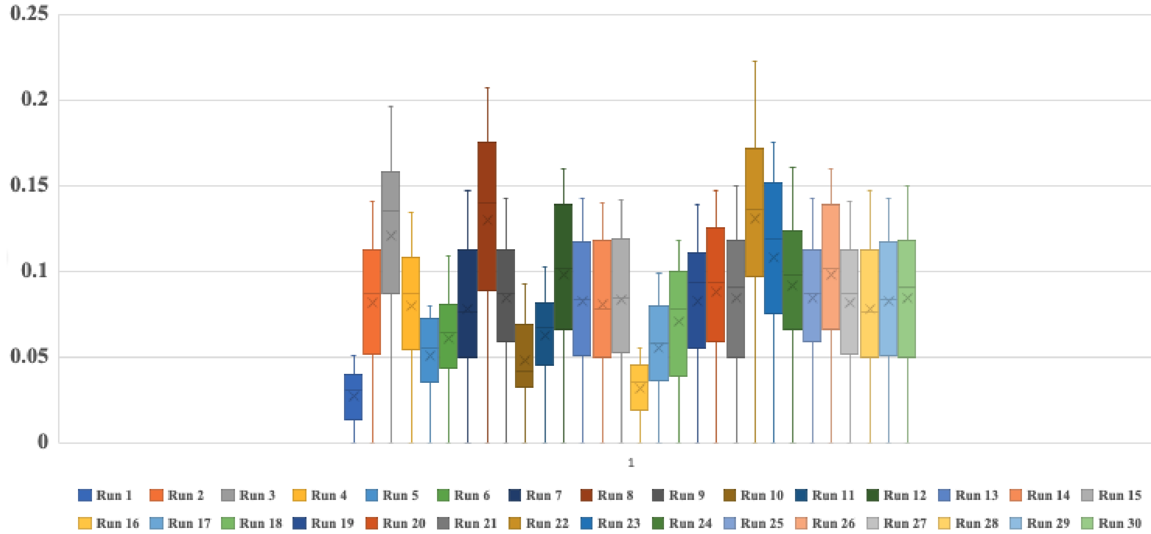


Fig. 11. Boxplot of the fraction of acknowledged nodes in UoM-SC using Spray & Wait routing protocol for 30 runs

The results demonstrate that this protocol achieved a substantial coverage area while involving a minimal number of participating nodes. This outcome indicates a low network load, suggesting that future research should focus on further developing on this protocol to enhance its reliability within specific applications where resource efficiency and scalability are crucial.

In addition to the aforementioned analysis, the results should be proved statistically significant. To this end, the variations of the approaches used in this work are tested using one-way Analysis of Variance (ANOVA). A regression model is built and two hypothesis testing are assumed for each evaluation metric as follows:

Messages Consumption:

H0: The mean number of messages of all the routing protocols are equal:

$$H0{:}\ \mu_{Broadcasting}(messages) = \mu_{Probabilistic\ Flooding}(messages) = \mu_{Spray\ \&\ Wait}(messages)$$

H1: The mean number of messages of all the routing protocols are NOT equal:

$$H1{:}\ \mu_{Broadcasting}(messages) \neq \mu_{Probabilistic\ Flooding}(messages) \neq \mu_{Spray\ \&\ Wait}(messages)$$

Acknowledged Nodes:

H0: The mean number of acknowledged nodes of all the routing protocols are equal:

$$H0{:}\ \mu_{Broadcasting}(a-nodes) = \mu_{Probabilistic\ Flooding}(a-nodes) = \mu_{Spray\ \&\ Wait}(a-nodes)$$

H1: The mean number of messages of all the routing protocols are NOT equal:

$$H1{:}\ \mu_{Broadcasting}(a-nodes) \neq \mu_{Probabilistic\ Flooding}(a-nodes) \neq \mu_{Spray\ \&\ Wait}(a-nodes)$$

Time:

H0: The mean number of acknowledged nodes of all the routing protocols are equal:

$$H0{:}\ \mu_{Broadcasting}(time) = \mu_{Probabilistic\ Flooding}(time) = \mu_{Spray\ \&\ Wait}(time)$$

H1: The mean number of messages of all the routing protocols are NOT equal:

$$H1{:}\ \mu_{Broadcasting}(time) \neq \mu_{Probabilistic\ Flooding}(time) \neq \mu_{Spray\ \&\ Wait}(time)$$

The significance level (confidence) used in this test is 95% ($\alpha = 0.05$). The results of the ANOVA of all the three models shows that the p-value is less than the 0.05, this means the null hypothesis for all models are rejected. In other words, the results of this work is considered statistically significant.

Furthermore, compared to previous studies, this study contributed to developing a general strategy for designing an emergency network on a smart campus using real data. This strategy involves several stages, including collecting information, performing the simulations, evaluating the performance, and performing statistical analysis to construct a correct hypothesis for the design. The studies mentioned in this work investigated various application mechanisms and message transfer strategies, but this study focuses on choosing the right routing protocol in delay-tolerant networking for a specific application. Table 5 presents a comparison between this work and results of similar works in the literature that use the same routing protocols and perform the experiments under similar conditions and metrics used in this work. The benchmarking shows that Spray & Wait used in the adopted smart campus environment outperformed the other studies in terms of the number of acknowledged nodes. However, the use of Broadcasting protocol is usually used for benchmarking purpose, but it was decided to include it in the comparison to show its performance in our designed environment. Finally, the authors believe that adopting adaptive strategies for smart campus is better than using one routing protocols. However, this thesis statement needs more investigation when it comes to real-time applications.

Table 5. Benchmarking the results with the literature

Study	Algorithm	# of Dynamic nodes	# of messages	Ration (# of messages/ # of nodes)	# of Acknowledges nodes (approximate)	Ratio of acknowledged nodes (# of nodes/ # of messages)
This work	Spray & Wait	4219	565.29	13.3%	3543	**84%**
	Broadcasting	4219	3712	87%	4176	99%
Falcao et al. (2021)	Spray & Wait	36	16	44%	14.58	40.5%
	Broadcasting	36	16	44%	15.54	43.1%
Hasan et al. (2023)	Spray & Wait	250	-	-	220	88%
Putra (2023)	Spray & Wait	200	9	4%	60	3%
	Broadcasting	200	67	33%	136	68%

4. CONCLUSIONS

This work designed experiments to measure the performance of different protocol used in smart campus in terms of resources consumption. To validate the performance of this study, scenarios were proposed to reflect real world situations that can be happened smart campuses such as the UoM-SC. The simulations were performed aiming at evaluating their performance in terms of the places covered by communication range, number of data messages distributed within the simulation environment, and the number of nodes that received data messages. Three routing protocols, namely; broadcast, probabilistic flooding, and spray & wait are involved and benchmarked. The results showed that the better selection of the routing protocols for smart campuses is based on the application required in campus. EMOR solution can be considered a novel approach since it is hybrid, simple to implement, and useful in many emergency situations. It is simply considered an adaptive routing protocol where protocol changed every time and based on the situation or the service needed. These results are useful in emergency cases that may happen in the UoM-SC. It should be mentioned that the UoM-SC can adopt this kind of approaches since its network infrastructure is able to secure the resources needed in the proposed kind of routing.

As future work, more routing protocols and scenarios can be implemented and evaluated aiming to have better insights about emergency situations. In addition to the designed experiments mentioned earlier, further studies can be conducted to establish EMOR as a standard for alternative network applications in smart cities. For instance, PRoPHET routing protocol may be efficient in emergency situation, which should be investigated in the future works. Moreover, another direction can be considered in the future studies such as varying the movement patterns within the environment and measure the impact of these patterns on the whole network performance in emergency situations. For example, the network model in this work considers human as the carrier of the mobile nodes. Therefore, other carries should be investigated such as automobile or drones.

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