

A Queuing Model to Evaluate the Network Performance Considering the Heterogeneity and Mobility of Relay Nodes in Disaster Area

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Abstract This study presented a generic model that provided better QoS for integrated Human-to-Human and Machine-to-Machine communication with various characteristics. The fundamental problem, especially in a congested system, is to improve the system's effectiveness to satisfy the expected Quality-of-Service level for the integrated communication services since these have mutual interference. Here, the impact of buffer capacity on these services and the effect of heterogeneity and mobility of relay nodes on overall system performance are analyzed to develop a generic model for overcoming this problem. Therefore, the comparative results presented provided a new perspective to carry out threshold analysis with the system capacity and system performance by clarifying the effects of various factors, such as the cost of Machine-to-Machine traffic over Human-to-Human traffic, velocity, and heterogeneity of mobile nodes. According to the numerical results presented, unlike the previous studies, it is possible to use a single buffer to treat the integrated services from the buffering point of view without applying the reservation policy for any service, even for highly utilized systems. The results are also validated using discrete event simulation with less than %5 discrepancy.

Key-words: Disaster network; H2H and M2M communication; mobility aspects; buffer management; performance analysis.

1. Introduction

Network developers generally aim to minimize costs and maximize commercial network performance. Therefore, the cost of improving networking capacity and coverage issues makes the design and development process challenging in providing seamless communication for unexpected catastrophic events.

Developing progress for commercial networks is carried out considering the performability analysis of the proposed network due to the possible breakdowns of the servers. However, unforeseen biotic or abiotic events can destroy the entire network's infrastructure. Because of the physical destruction of network components and disruption in supporting network infrastructure in the affected area, the available networks around the affected area get congested [1]. Interruption of communication may lead to chaos and increase significantly in the number of deaths of more victims. Therefore, providing uninterrupted communication for highly utilized systems, even over long distances, is urgent and highly significant [2].

Even if the network becomes highly utilized after a disaster, it may be possible to maximize both the network coverage and its performance by minimizing the traffic load by taking advantage of pedestrians' and vehicles' mobility. Most Internet users in a disaster area are mobile users, so the analyses are required to include mobility issues. However, most mobility models that have been developed need to consider the effect of the relay nodes on the network performance when they join and leave the network.

Besides the relay mobility issues, providing Human-to-Human (H2H) and Machine-to-Machine (M2M) services gained wide acceptance for mobile systems for better communication in disaster cases. In an emergency, the network infrastructure must provide service priority consent for H2H real-time (delay-sensitive) traffic over M2M non-real-time (packet loss-sensitive) traffic. This service policy may also lead to massive traffic for the integrated H2H and M2M communication, which may cause an overloaded network. An impeccable network should buffer H2H and M2M packets to protect urgent data from being lost from unexpected disconnection. Here, reasonable buffer management policies to obtain the ideal resource sharing with service priority to the H2H communication may decrease the network congestion [3]. For H2H services, in most systems, packets are blocked if the channel reserved for them is unavailable. We want to explore what happens if we queue H2H packets to reduce blocking. Queuing will increase the latency, but it is okay; if the heterogeneity and mobility of relay nodes positively affect the system performance to meet the temporal constraints for H2H packets. For M2M packets, we want to avoid high blocking rates because most of the data connections on the Internet are reliable (TCP/IP); hence, the system retransmitted the dropped packets, leading to higher resource utilization. Here, it is required to prioritize H2H packets while maximizing buffering [4, 5].

Queueing system optimization can be divided into two groups: design optimization and system control optimization. Queueing-related optimization problems were rarely studied from the perspective of a control system approach [6]. In general, the integrated optimization approaches remodel the analytical model into the optimization model for system tractability and clearly define the objective function and the constraints of the model in the optimization routine. Large Continuous Time Markov Chains (CTMCs) may be scaled down by using the tensor product (TP) based mode transformation approach to handle the high number of equations that lead to challenges in the computation of the queueing systems [7]. Similarly, manifold optimization with Hybrid Precoding (HP) may reduce the system complexity considering the manifold structure and system characteristics [8]. While developing the optimization framework, it may be necessary to discuss the mental processes approaches, where queueing system optimization for customer behavior is a challenging issue due to their expectations of customers [9]. Therefore, experiment-based approaches [10] can be developed to represent real-life applications considering the queueing systems' characteristics, where meta-heuristic algorithms can be applied to complex processes [11].

The proposed optimization approaches concluded that queueing system factors must be first

considered to prove the structural results and then formulate the optimization problem [12]. Therefore, this study provided an overview of multi-dimension integrated service modeling from a queueing theory point of view by focusing on developing the theoretical framework to analyze and evaluate the system’s behavior. The aim was to carry out the threshold analysis to fulfill the performance metrics requirements for providing better quality of services (QoS), where the system may converge and settle down in the long run. The results may be considered for pairing system constraints in optimization routines [13].

Developing the theoretical model to analyze the network capacity considering the integrated services and the effect of relay node mobility on the traffic load can significantly describe the system behaviors. Here, this study investigates ways to integrate H2H and M2M services by considering the heterogeneity and mobility of relay nodes. Discussing and providing the results of the following research questions is expected to shed light on the network developer to increase the performance and minimize the cost for sustainable long-distance communication, which is vital in an emergency. The research questions for this study were:

1. How do we serve H2H and M2M packet requests to support several applications of different types to provide the best QoS possible for multi-service traffic, considering the relay node heterogeneity and mobility?
2. Can H2H packets be buffered in an emergency for a highly congested network?
3. Can service priority be treated differently from buffer management to improve performance for different traffic types?

This study aims to present an analytical model that accounts for all the research questions above so that a developed QoS framework can provide better performance for integrated H2H and M2M communication traffic over the Mobile Internet. The model improved by using queueing theory and the two-dimensional Markov process. Here, the presented numerical analysis includes various system parameters for performance metrics. Table 1 lists the abbreviations used in this paper with their explanations, and the paper’s organization is as follows:

Table 1. List of abbreviations

Abbreviation	Explanation	Abbreviation	Explanation
λ^{h2h}	Mean arrival rate for H2H packets	λ^{M2M}	Mean arrival rate for M2M packets
μ^{h2h}	Mean departure rate for H2H packets	μ^{M2M}	Mean departure rate for M2M packets
ρ^{h2h}	Traffic load for H2H packets	ρ^{M2M}	Traffic load for M2M packets
μ_{cd}^m	Mobility transition rate	cd_t^m	Cell dwell time
P^p	Pedestrian ratio	r	Radius of the cell
P^e	Perimeter of the cell	C_A	Area of the cell
$E[v]_{ped}$	Average velocity for pedestrians	$E[v]_v$	Average velocity for vehicles
L	Buffering capacity for both H2H and M2M packets	L^{h2h}	Buffering capacity for H2H packets
S	Number of channels	MQL^{h2h}	Mean Queue Length for H2H packets
MQL^{M2M}	Mean Queue Length for M2M packets	RT^{h2h}	Response Time for H2H packets
RT^{M2M}	Response Time for M2M packets	BP^{h2h}	Blocking Probability for H2H packets
BP^{M2M}	Blocking Probability for M2M packets	C_{M2M}^{h2h}	Impact of M2M traffic on H2H traffic

The following section presents the theoretical background. All the published papers discussed in Section 2. considered the network’s performance under different situations. Although the effect of node’s mobility on the system performance was the main focus for some of them, none of them has discussed and provided the threshold analysis for the network performance metrics considering the buffering for service admission control and mobility aspects of relay nodes and their impacts on integrated H2H and M2M traffic (see Table 2, in [39]). While Section 3. describes the proposed model and the solution techniques used for the system analysis, Section 4.

presents numerical results for the performance measures. In Section 5., relevant conclusions addressed the efficiency of using the single buffering approach and its contribution to maximizing the overloaded system performance for the integrated system.

2. Theoretical Background

Over the past several years, there has been a considerable amount of research in the field of QoS-guaranteed traffic models for analyzing network performance and the effect of mobility models on communication services [14, 15]. According to the authors in [16], while some mobility models did not consider the effect of mobility on integrated services, some studies discussed the relay node's mobility on network performance but without considering the mutual interference and the level of performance of integrated H2H and M2M services. Mobility allows the relay node to move in and out of the affected coverage area in a disaster case. The constitutional idea here is to use the node's mobility to exchange information continuously. When the scale of the disaster area is sparse, using the mobility aspects to maximize the network performance becomes more inspirational [17]. However, every node in the network is independent of joining in and leaving the network, and this may lead to increased traffic and a high packet loss ratio or decreased transmission ratio regarding the speed of the mobile nodes for integrated services since they use the shared resources [18].

In [19], node mobility and intensity were considered to evaluate their impact on the performance of routing protocols for overused communication in disaster scenarios. Therefore, the MaxProp forwarding model used the congestion control mechanism by buffering the messages to obtain the best delivery ratio as a function of the number of nodes and messages. However, the effect of the mobility aspects, like the node's velocity, on network performance should have been considered. In [20], dynamic path and destination selection-based mobility models using the ant colony systems were developed, which provided the best path selection from the node to the source for the fixed number of mobile nodes. The authors also stated that an analytical model is required to consider the effect of the node intensity on network performance to increase the quality of the assurance for the provided integrated services for a realistic large-scale mobility model.

The authors conducted comprehensive emergency communication and management research in [21]. They concluded that it might be possible to utilize the network performance for better QoS by analyzing the network congestion and providing the threshold analysis for various network constraints and limited resources. Here, using buffer management considering the packet admission policies and scheduling aspects to prevent traffic congestion is essential to manage data transmission [22], [23], [24]. Authors in [25] discussed the impact of mobility in dense networks. According to the authors, the throughput decreased as the number of mobile nodes increased for both the Markovian and Fixed-Point approximation models. This study only provided limited results regarding a single service type's throughput. Therefore, the model needs to update and ensure buffering and threshold analysis to maximize the throughput while minimizing the mutual interference of the integrated services. In [26], the authors developed a buffer management and scheduling scheme to minimize the blocking probability of the integrated voice and data services. The main idea was to provide access to the entire buffer for the highest priority call. This resulted in an upsurge in queueing delay and the blocking probability for the non-real packets. The authors in [27] developed a scheduling algorithm to differentiate the H2H and M2M traffic under heavy traffic. Even though the scheme developed provided better performance for H2H communication, the results should include an analysis of the effect of massive H2H traffic

on M2M traffic to minimize mutual dependence.

In [28], the authors presented a new analytical model considering the mutual dependence between the serviced traffic to evaluate the blocking probability. However, they should discuss the effect of mobile users on the system's performance. The paper in [29] provided an approximate solution for the proposed model, where a queueing policy based on preemptive policies is applied and treated for multi-class services. In this study, the author stated that the results provided needed to be more reasonable for the highly utilized system. Besides this, the model should include mobility aspects. According to the authors in [30], prioritizing the packets transmitted in the emergency network is a solution to provide service guarantees for packets with various delay requirements. When the packet density of each priority increases, the transmission success ratio decreases because the packet queueing delay of each priority at the node increases as the number of packets increases.

In [31], a reservation-based call admission control scheme decreased only the forced termination probability for handoff packets; however, this increased the blocking probability for originating packets. In [32], a similar approach was applied to reserve Machine-to-Machine (M2M) shortest data in the primary service unit (BBU). According to the results, reserving policy leads to less utilized resources despite decreasing the blocking probability for H2H traffic. Therefore, it may be better to refrain from using a reservation policy and take advantage of queueing both H2H and M2M type packets to ensure high resource utilization while providing reasonable QoS for different services.

The dual threshold bandwidth reservation (DTBR) method was used to allocate dynamically and ultimately share the packets on the channel [33]. In [34], the authors stated that a non-prioritized traffic strategy to handle H2H and M2M traffic is more suitable for emergencies. However, in these studies, different types of packets were treated similarly without considering the buffering policies to eliminate the blocking of low-priority packets. However, this led to an increased blocking probability of real-time packets for heavy traffic conditions where the network became overloaded for non-real packets. In [35], a dynamic channel allocation scheme with channel borrowing provided better performance and lower blocking probability for originating real-time calls. However, this increased service cost since the reservation threshold was required to be recalculated based on traffic load, and the CAC schemes had to monitor the traffic for specific periods. The authors in [36] proposed a Dynamic Grant Time Interval (AGTI) scheduling scheme. They compared it with the Fixed AGTI scheme, where resource sharing and utilization provided better results for Long Term Evaluation (LTE) systems. Here, the scheduler complexity increased due to resource usage monitoring issues and the reassigning process to locate the M2M and H2H traffic to the most appropriate channels.

3. Model Description and the Solution Techniques for the Proposed System

This section mainly explains the proposed scenario and the model to deliver seamless communication through User Equipments (UEs) for integrated H2H and M2M traffic in Fig. 1. According to the scenario illustrated in Fig. 1a, mobile relay nodes travel independently in or out of the disaster area and generate H2H and M2M packets. The nearby nodes can set up connections via relay links and transmit packets to each other. When the mobile relay node connects to a base station, it can send the information directly to the rescue center. If the mobile relay node is not connected since it is out of the base station coverage area, it transmits the latest data to

the very close UEs. This data content finally reaches the Rescue Center via the operative base.

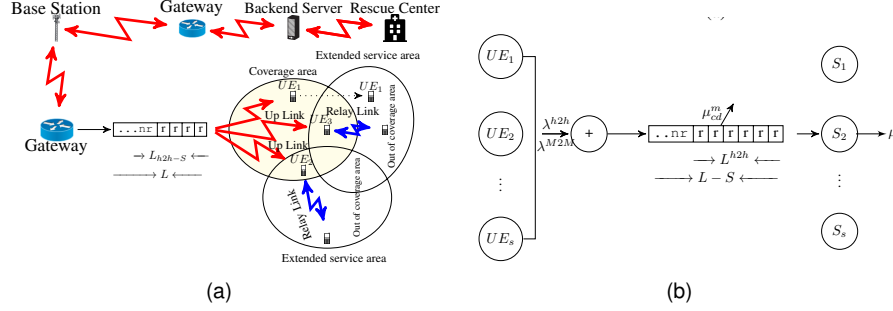


Fig. 1. The scenarios (a) and (b) for the proposed model.

Fig. 1b shows the queuing model developed for multi-channel systems (S) with a single queue, considering the mobility issues of relay nodes. It represents the data flow of multi-UE devices within the coverage area of a base station with S channels backing the users outside the coverage area. Integrated H2H and M2M packets share a single finite queue with the maximum buffer size $L - S$ according to the pre-emptive policy, where delay-sensitive H2H packets have priority over M2M packets. As all the channels are busy serving the H2H data packets, the incoming H2H packets join the queue up to L^{h2h} if the total number of H2H and M2M packets is less than $L-S$. When there are no H2H packets on the system, the M2M packets can use the total buffer capacity. The system does not accept new M2M packets joining the system where the maximum buffer size, $L - S$, is only complete. However, since the proposed system has a single queue with multiple channels, H2H and M2M data packets can be served simultaneously without preempting the M2M packets from the channel if the total number of H2H packets in the system is less than the number of channels. For the proposed model, we assumed that the arrival of both the H2H and M2M packets have Poisson distribution with mean arrival rates λ^{h2h} and λ^{M2M} respectively and packet service time is assumed to follow an exponential distribution with means $1/\mu_s^{h2h}$ for H2H packets and $1/\mu_s^{M2M}$ for M2M packets.

Let cd_t^m be the cell dwell time for a mobile node in the coverage area. It is assumed to follow an exponential distribution with a mean of $1/cd_t^m$ for H2H and M2M traffic. Here, it is given by the equation

$$cd_t^m = \frac{E[V]_a P}{\pi C_A}, \tag{1}$$

where $E[V]_a$ is the average speed of the mobile nodes, P and C_A are the perimeter and the area of the cell, respectively. Diversity in the density of the pedestrian and vehicle nodes leads to changes on $E[V]_a$ according to the speed of mobile nodes, which is directly proportional with cd_t^m . Hence, the cell dwell time in equation (1) becomes

$$cd_t^m = \frac{(P_{ed}^r E[V]_{ped} + (1.0 - P_{ed}^r) E[V]_v) P}{\pi C_A}. \tag{2}$$

Let μ_{cd}^m be the mobility transition rate. The calculated cd_t^m value in equation (2) and the utilization of both H2H and M2M traffic affect the value of μ_{cd}^m . Hence, it can be expressed by the equation

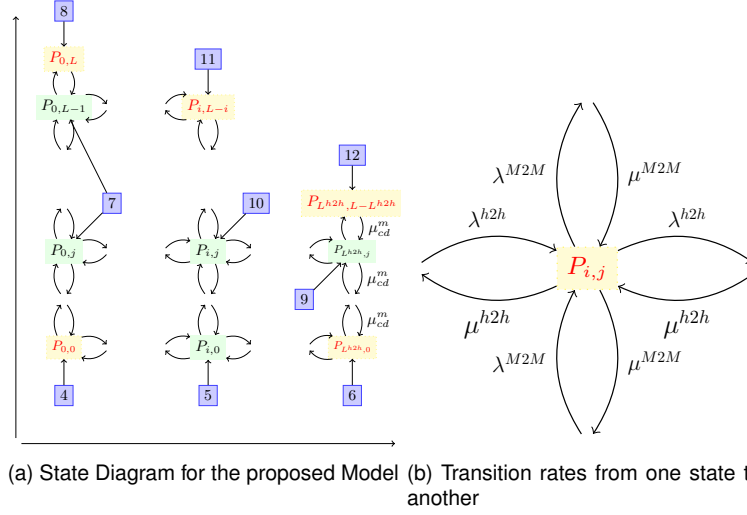


Fig. 2. State diagram for the proposed integrated H2H and M2M communication.

$$\mu_{cd}^m = \begin{cases} icd_t^m & \text{if } i \geq 1 \text{ and } i \leq L^{h2h} \\ jcd_t^m & \text{if } j \geq 1 \text{ and } j \leq L \end{cases} \quad (3)$$

The queuing model in Fig. 1b can be modeled as a two-dimensional Birth and Death Markov Chain, which is an irreducible Markov process on a lattice strip with a path (transition) and positive probability from every other state, as shown in Fig. 2. For Fig. 2a, forward and backward lateral transitions with λ^{h2h} and μ^{h2h} rates (see Fig. 2b) show possible events for the packets joining to the system and departure from the system for H2H packets. On the other hand, upward and downward transitions present M2M packets to join and depart the system with the rates of λ^{M2M} and μ^{M2M} accordingly (see Fig. 2b). The possible departure of mobile nodes from the system affects the system load, resulting in changes in the downward and backward lateral transition rates with μ_{cd}^m given in equation (3). Here, the total departure rate μ can be defined as follows:

$$\mu = \begin{cases} \mu^{h2h} = \min(i, S)\mu_s^{h2h} + \mu_{cd}^m & 1 \leq i \leq L^{h2h}, 1 \leq S \leq L^{h2h} \\ \mu^{M2M} = \min(j, S-i)\mu_s^{M2M} + \mu_{cd}^m & 1 \leq j \leq L, 0 < S-i \leq L^{h2h} \end{cases}, \quad (4)$$

where μ^{h2h} and μ^{M2M} are mean departure rates of the system for M2M and H2M packets. Therefore, M2M data packets do not take service for the states on the rightmost column in Fig. 2a numbered 6, 9, and 12, where all channels are busy serving H2H packets. Here, it is possible to have a downward transition only with μ_{cd}^m in equation (4) since the packet departure from the system is not only limited due to the service given to the packets for M2M communication. The notation by $P_{i,j}$ is used for the steady-state probability that there are i -type H2H packets and j -type M2M type packets according to the state diagram given in Fig. 2a with the transition rates in Fig. 2b.

An algorithm is developed to generate the full transition rate matrix to find the state probabilities for a finite lattice (see Algorithm 1 and Appendix in [39]). Performance measures such as

Mean Queue Length (MQL), Throughput (Thr), Response Time (RT), and Blocking Probability (BP) for both H2H and M2M traffic can be calculated using state probabilities obtained from the balance equations (see Section 3 in [39]). Besides the exact solution technique, the Discrete-Event Simulation (see Algorithm 2 in [39]) technique is also used independently to validate the analytical model, which is fast and has a %95 confidence level.

4. Numerical Results

This section discussed the effect of the integrated H2H and M2M services on network performance, considering the mobility aspects for both pre-disaster and post-disaster cases. The numerical results in this section shed light on the significance of developing the theoretical framework to build the best infrastructure based on the heterogeneity and mobility of relay nodes in the disaster era to provide seamless and high-quality service. The obtained fundamental and theoretical results can be the basis for developing the optimization framework for real-life applications. Different solution techniques were used in computing the steady-state probabilities for model-based quantitative evaluation considering the system-specific parameters provided in Table 2 (see Section 4.1 in [39] for system parameters calculation).

Table 2. Parameters used for analysis

Parameter	Value	Parameter	Value	Parameter	Value
λ^{h2h}	Variable	λ^{M2M}	Variable	μ^{h2h}	25.42 packets/s
μ^{M2M}	1.57 packets/s	ρ^{h2h}	[0.1-0.99]	ρ^{M2M}	[0.1-0.99]
L^{h2h}	Variable	L	Variable	S	8
$E[v]_{ped}$	4.32 km/h	$E[v]_v$	50 km/h		

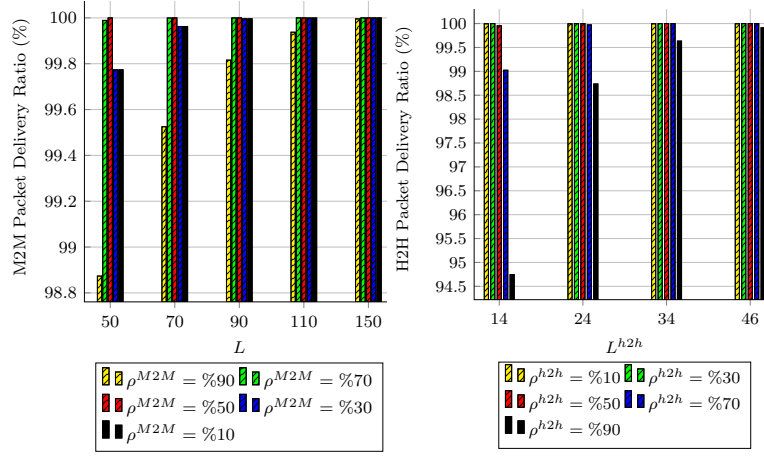
The M2M traffic may dominate the network system and increase the number of blocked H2H packets for multi-channel systems. Maximizing the performance of the system is possible with a reasonable buffer capacity. Threshold analysis considers the response time and the delivery ratio for M2M and H2H packets to find the acceptable buffer capacity for increasing the system performance. Optimum capacity analysis for L and L^{h2h} is significant to minimize the H2M packets to be blocked. Here, the blocking probability due to the presence of M2M packets, C_{M2M}^{h2h} , can be obtained as follows:

$$C_{M2M}^{h2h} = P_{0,L} + P_{1,L-1} + \dots + P_{L^{h2h},L-(L^{h2h})}, \quad (5)$$

where P denotes the top diagonal states probabilities in Fig. 2a.

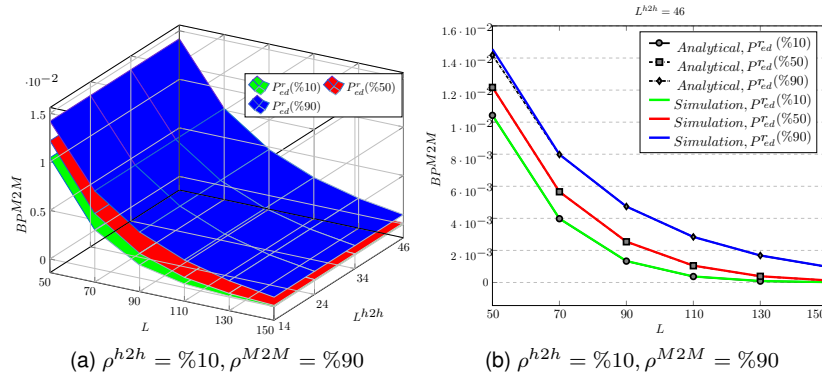
The analysis carried out for Fig. 3 shows that it is possible to use a single queue to minimize the blocking probability for H2H and M2M packets because C_{M2M}^{h2h} , in equation (5), goes to zero for larger buffer sizes. Hence, once the buffer size is large enough, we do not need to separate the queues for different traffic types since this allows us to reduce the correlation between them. Figures 3a and 3b represent the M2M and H2H packet delivery ratio as a function of the traffic load in percentage and the buffering capacities of L and L^{h2h} for M2M and H2H packets. When L and L^{h2h} are not enough to cope with heavy data load, C_{M2M}^{h2h} increases, decreasing the number of packets delivered successfully. The results indicate that the M2M packet delivery ratio slightly reduced in peak data traffic load for smaller L values. On the other hand, the H2H data delivery ratio decreased sharply to around 22%. Therefore C_{M2M}^{h2h} goes to zero for larger buffer sizes when $L = 150$ and $L^{h2h} = 46$.

Fig. 4 is given for BP^{M2M} versus L and L^{h2h} values considering the density of pedestrians in the disaster area. Fig. 4a shows that when M2M traffic dominates the system, BP^{M2M}



(a) $L^{h2h} = 46, P_{ed}^r = \%30, C_{M2M}^{h2h} \approx 0$ (b) $L = 150, P_{ed}^r = \%30, C_{M2M}^{h2h} \approx 0$
Fig. 3. Data delivery ratio as a function of L and L^{h2h} for different data loads.

increases as the pedestrians' ratio increases. Here, the delivery ratio for M2M packets decreased as well. When the pedestrian ratio increases, the average velocity of the mobile nodes decreases, affecting the system performance negatively. However, increasing the buffer size L can minimize the BP^{M2M} . Therefore, increasing the buffer size to $L = 150$ for different L^{h2h} values shows that BP^{M2M} is less than 0.01, where the mobility heterogeneity of nodes does not affect the M2M packet delivery ratio. Fig. 4b shows the results obtained using analytical and simulation techniques, where $L^{h2h} = 46$ for different L values.



(a) $\rho^{h2h} = \%10, \rho^{M2M} = \%90$ (b) $\rho^{h2h} = \%10, \rho^{M2M} = \%90$
Fig. 4. Data delivery ratio as a function of L and L^{h2h} for different data loads.

Fig. 5a represents the RT^{h2h} for L and L^{h2h} with different pedestrian ratios together with the delivery ratio of H2H packets. As L^{h2h} increases, RT^{h2h} increases for any L value. Increasing the mobile relay nodes does not significantly affect the RT^{h2h} . Here, the results show that RT^{h2h} is less dependent on L and the ratio of pedestrians since H2H packets have service priority. On the other hand, the RT^{h2h} can be minimized by L^{h2h} and L capacities, where increasing them

further than 46 and 150 for the buffer sizes of L^{h2h} and L respectively does not affect RT^{h2h} anymore. Here, it converged to its maximum value of approximately 67.8 ms.

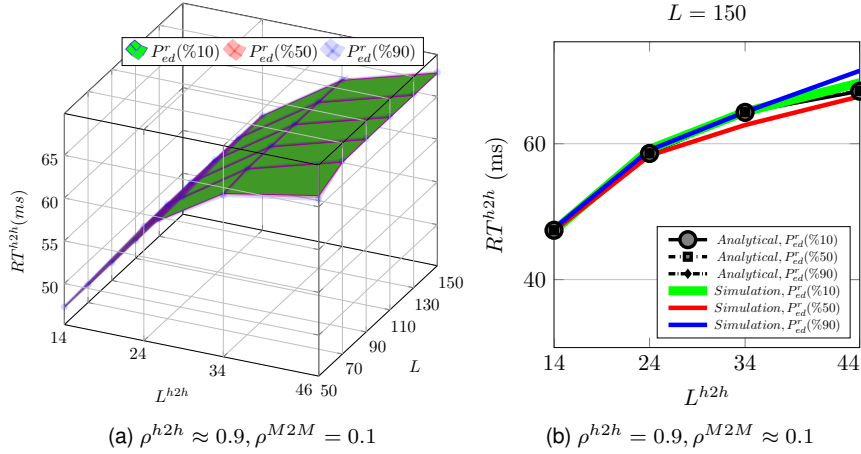


Fig. 5. RT^{h2h} as a function of L^{h2h} and L .

Fig. 6 shows the increase in MQL^{M2M} and MQL^{h2h} for L considering the percentage of pedestrians in the system. In Fig. 6a, MQL^{M2M} increases when there is a rise in the number of pedestrians for any L values. There is also a progressive growth in MQL^{M2M} when L becomes larger for different numbers of pedestrians on the system; however, increasing L further than 150, when $L^{h2h} = 46$, does not affect the system performance even if the number of pedestrians changes dynamically. Because MQL^{M2M} becomes less dependent on mobility for larger L values. Besides this, MQL^{h2h} is given as a function of both L^{h2h} and P_{ed}^r in Fig. 6b. MQL^{h2h} increases as L^{h2h} increases for different P_{ed}^r . The effect of mobility on MQL^{h2h} is insignificant as L^{h2h} increases when $L = 150$. The major contribution of the results presented can be summarized as follows:

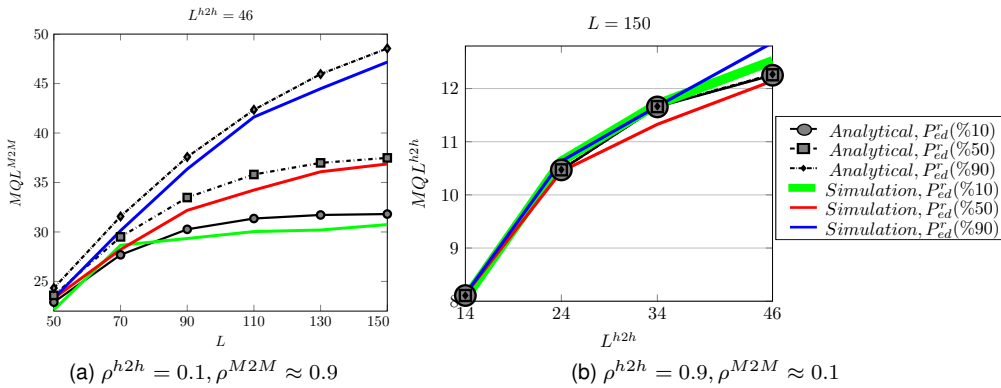


Fig. 6. MQL^{M2M} and MQL^{h2h} results as a function of L for highly utilised M2M and H2H communication.

The proposed $M/M/C/L/L^{h2h}$ system behaves like a well-known $M/M/C/L$ when the impact of M2M traffic on H2H traffic converges to zero. Based on the buffer management analysis, it is evident that better performance can be obtained by using the single buffer instead of using the reservation policy and underutilized buffers for both H2M and M2M packets (see Fig. 3). The proposed service priority approach for the emergency packets can be treated differently from the buffering point of view. The results show that it is possible to buffer H2M packets with a reasonable response time while minimizing the M2M packets to be blocked (see Figures 4, 5, and 6). The simulation results are given comparatively with the mathematical results regarding discrepancy in [39].

5. Conclusion

This paper offered an essential framework for research by presenting an analytical model that supports mobility issues for integrated H2H and M2M traffic schemes. Buffer management analysis that considers mobility issues effectively finds functional spaces. The proposed model shows that channel reservation is only one of many ways of serving prioritized packets. The integrated services can meet the predefined QoS requirements with different service prioritization and buffer management strategies. Both H2H and M2M traffic can be served according to their needs, i.e., an H2H packet has low latency while allowing a small fraction to be dropped, while data packets can have high latency by using large buffers, but they are not dropped. In general, H2H packets can be queued in standard networks, but the contribution is also valid in mobile systems for highly utilized networks. Please also note that L and L^{h2h} are dominant parameters to provide the satisfying quality of H2H service and minimize the effect of mobility on the system performance. Using C_{M2M}^{h2h} shows that large buffers (not infinitely large, $L = 150$ and $L^{h2h} = 46$ are maximum) can lead to uncorrelated handling of both H2H and M2M types services and hence avoiding the need to separate queues. Because memory/storage is relatively cheap, the solution presented is suitable for network infrastructure. The results also show that future dynamic queue management algorithms should consider traffic class characteristics and mobility aspects to provide efficient routing algorithms in multi-server environments as proposed in [37], [38]. Developing a generalized framework here is vital for better communication with the rescue center to reduce rescue time and improve organization in a disaster case.

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