PERFORMANCE ANALYSIS OF IOT NETWORKS WITH MOBILITY VIA MODELING AND SIMULATION

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ABSTRACT

The Internet of Things will connect a large number of devices to the Internet. One of the most critical components of an IoT network is the network mediator, as it is a traffic concentrator. Therefore, the growth of such networks is largely dependent upon its capacity. In order to establish such limits, in this work we present a simulation model and the performance analysis of the traffic generated by devices connected by the IoT, aiming at dimensioning the capacity of an IoT mediator. The simulation model is based on both discrete event and Random Waypoint simulation for an AdHoc network that accommodates clusters and the effects of mote mobility. We analyze through a case study the mean-queuing time and the CPU utilization for the cluster-heads (i.e. output CPU) in each cluster, given the probability of connectivity of the motes resulting from their mobility and transmission power. Through the model, it is possible to estimate the incoming and the outgoing traffic for each cluster and for the IoT mediator. The proposed simulation model is general in that it captures a number of features of complex IoT systems, including the mediator, gateways, emergency nodes, Internet connections and also distinct types of IoT traffic such as the one generated by RFID tags and sensor systems.

Keywords: IoT Mediator, dimensioning, RFID, Random Waypoint, Jackson networks.

1 INTRODUCTION

The Internet of Things (IoT) adopts simple and open technologies that have been consolidated in the telecommunications arena. It has targeted applications with direct impact in the world economy and society, such as Environmental, Energy (Smart Grid), Transportation, Healthcare, etc.

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The use of RFID tags is also relevant for the identification of medical equipment, patients, caregivers, and medicine, among others. A key element in any IoT network is the so-called mediator, which is the device that concentrates the IoT traffic. It also accomplishes the preprocessing of data (i.e. filtering, classification, grouping, aggregation etc.). The mediator relieves the applications from the sensor acquisition task. IoT modeling, simulation, and emulation may be applied to two domains of wireless technologies: network coverage and (node and link) capacity. This work is concerned with the dimensioning of node/cluster capacity and the estimation of mean network delay, taking into account mote connectivity. More specifically, we investigate through a case study the mean queuing time and the CPU utilization for each cluster for a given probability of connectivity of the motes resulting from the mobility.

A discrete-event network simulation model (DES) allows an approximate placement of the sensor nodes and RFID in a cluster, as well as their approximate traffic load, but it does not express their mobility. The mobility of nodes within a cluster may be added to a DES model through the Random Waypoint (RWP) algorithm (Pramanik, Choudhury, Choudhury, Arif, and Mehedi 2015) (Nassef 2010). A degradation in connectivity for some nodes may cause the overall reduction of the traffic in the upper layers.

The remainder of this paper is organized as follows: In Section 2 we review previous work. The network model is discussed in Section 3. A case study illustrating the application of the model is shown in Section 4. In Section 5, the results are discussed. We summarize and present our conclusions in Section 6.

2 RELATED WORK

The work by Karnouskos et al. (Karnouskos and d. Holanda 2009) introduces the simulation of a Smart Grid city using software agents, including home appliances, an electric car and a power generating plant. It was possible to create a dynamic infrastructure that simulates a future smart grid city. The work by Novak et al. presents a simulation of an integrated approach for a SCADA (Novák, Šindelář, and Mordinyib 2014), but within the context of industrial automation. Chunxiao Fan et al. present a Middleware (mediator) solution for RFID tags and ZIGBEE Sensor networks (Fan, Wen, Wang, and Wu 2011) and it offers API interfaces so that the applications do not need to deal with the sensor level of the network.

Lu and Yu present a K-coverage fuzzy optimization procedure using an algorithm for plant growth simulation (Lu and Yu 2014). The simulation results show the effectiveness of the proposed algorithm in comparison with other competing approaches. The work by Samaniego et al. (Samaniego and Deters 2016) concerns with the management of heterogeneous IoT resources and uses the model of virtual resources mapped onto physical resources.

However, none of these works covered in the literature tackle the traffic aspects of the network such as partial and global delays and CPU utilization. Instead, in this work, we tackle the performance of the queues, CPUs and traffic in an IoT network, which includes clusters of sensors from an AdHoc network, while varying the power transmission for each node to analyze node connectivity.

In the work by Ursini et al. (Ursini, Timóteo, Santos, and Martins 2014),(Ursini, Martins, Timóteo, and Massaro 2015) a virtual single-link IP network was simulated using the concept of incremental validation. The former consisted of only the elastic traffic whereas the latter considered the stream traffic. The work considered specific network parameters such as packet size and transmission rates. In the present work, we used more generic parameters (fixed packet size and transmission rates), a distinct type of traffic, adopted a new multi-link model with connectivity among nodes, and analyzed the performance of the IoT mediator.

In the paper by Leite et al. (Leite, Ursini, and Martins 2017) the authors considered only an AdHoc network (i.e. without IoT) for traffic analysis. The work consisted of the analysis of mean queue delay and CPU utilization in each cluster and a small blocking value caused by loss of connectivity was included. In the present work, we added an IoT Network to the topology, and we varied the power transmission value to analyze the loss of node connectivity. Furthermore, the network included more IoT services, which correspondingly generated more traffic such as the one from RFID and network management services (Simple Network Management Protocol - SNMP).

3 NETWORK MODEL

The network model is a hierarchy consisting of clusters which contain motes. A cluster may also have multiple output CPUs, thus allowing several parallel connections. Inherent in each queue is the waiting delay before a TCP/IP packet can be processed by a server. Clearly, both queuing and processing times are subject to statistical distributions. Therefore, a network cluster may be regarded as a set of internal queues (each one associated with an outbound link).

The network components are the mediator, gateways, clusters and endpoints. The endpoints can be RFID and sensors for different applications. Figure 1 shows the network model with its inputs (packets) and outputs (packets) to each cluster. The upper part of the model includes the RFID network, which is detailed as follows:

- Two RFID clusters (CLR_1, CLR_2), which perform the acquisition/input of RFID tags;
- Two RFID inputs, which receive data packets generated by IoT RFID tags (RFID reader);
- Internet, which models the traditional Internet.

A Mediator MD is shared by all subnets in the model, i.e. it performs the IoT mediation function and interconnects (physically and logically) with other network elements for the purpose of mediating data for applications.

The model adds four representative applications that process and consume the information leaving the mediator: 1) RFID, 2) Sensor, 3) SNMP management, 4) Smart Cities. These applications receive information from application gateways (GAs) and store them in databases. RFID information is all based on traffic generated by RFID tags (96-bit EPC-Global). The SNMP application offers two types of services: 1) Trap and 2) Command/Response. In typical IoT, the databases can be reached by mobile or cell phone applications through the secure HTTPS protocol.

The lower part of Fig. 1 is an AdHoc Network that generates data traffic which is aggregated by the IoT mediator. It consists of the following elements:

- Seven sensor clusters ($CLT_1 ....CLT_7$); these are non-mobile and homogeneous for the sake of simplicity. However, the model does not restrict the addition of heterogeneous clusters. Each cluster consists of n mobile nodes, where n is a configurable parameter. In our example, we used ten mobile motes (Fig. 1);
- Four gateways or Internet nodes ($GW_1 ....GW_4$); both GW_1 and GW_2 are output gateways; GW_3 is an emergency gateway, i.e. it is used as a backup gateway for GW_1, e.g. when the latter overflows its internal buffers; both GW_4 and GW_2 are protocol converters, i.e. they are used to integrate two subnets;
- Seven inputs: they model data packets generated by IoT sensors;
- Three Internet outputs: they model the flow of IP packets outbound;
- Mote mobility: the Random Waypoint algorithm for mobile AdHoc networks is employed;
- Mote contention: although the model accounts for contention, the internal contention between nodes in a cluster was assumed to be negligible in the case study (Section 4), since the delays on the cluster-head are of larger magnitude;

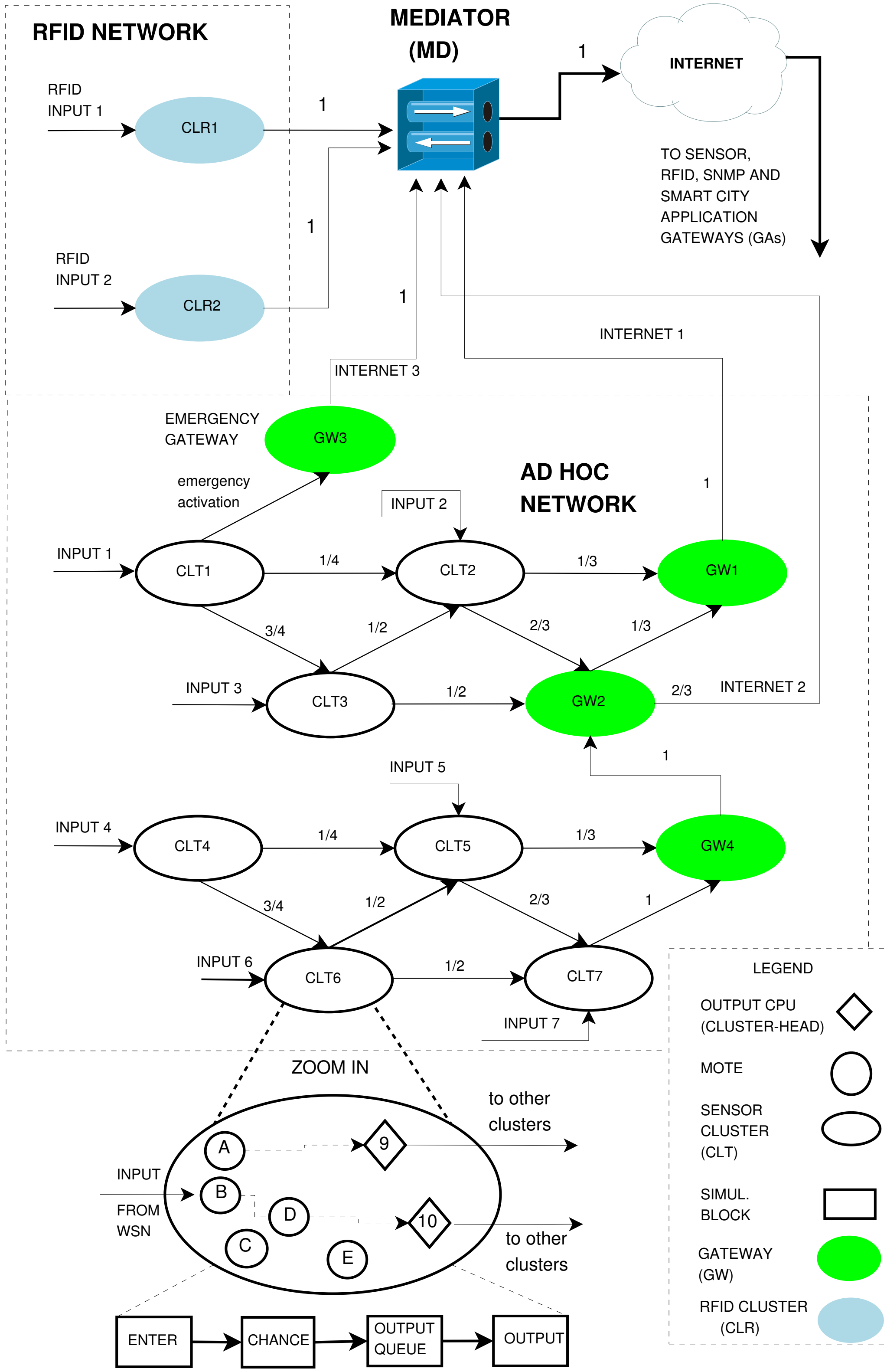

Figure 1: IoT network model.

- Input variables: data arrival and service time distributions in a node;
- Control variables: the probability of node connectivity in a cluster. This probability is provided by the Random Waypoint algorithm, which depends on a range of variables such as receiver threshold, area size, antenna type, height and gain, and system loss coefficient among others (Leite, Ursini, and Martins 2017);
- Output variables: mean queue time and mean CPU utilization on each cluster for a given position of the motes in the cluster.

Each cluster contains several motes (Fig. 1) and one or more output CPUs (cluster-heads), which are used for its output channels/links (Table 1). These output CPUs are fixed in our model (without sacrificing the quality of the results), although it is possible to configure them to have some limited degree of mobility as well. Motes share the output CPUs for relaying outbound traffic, provided that they have connectivity, i.e. they are within the power range of either an output CPUs or an intermediate node. The model is dynamic and the illustration is only a snapshot representation of an arbitrary instant t in time. For example, at instant $t+1$ it might be other motes that engage in outbound transmission.

Each cluster is modeled as four simulation blocks connected in series:

1. *Enter block*: the enter block simulates the arrival of a packet in a cluster. It counts the number of packets entering the cluster;
2. *Chance* is a 'decide block', and it distributes the packets across a set of outgoing lines, where each line is associated with an outgoing queue; an important parameter in this block is the probability of packet loss, and its value was obtained from the case study (Section 4). The probabilities of a packet being forwarded to an outgoing link are initially configured as shown in Fig. 1 (e.g. 1/4 from Cluster 1 to Cluster 2 and 3/4 from Cluster 1 to Cluster 3);
3. *Output queue* represents the queuing time in the outgoing line;
4. *Output cluster* simulates the output (i.e. forwarding) of packets from the cluster. It is also responsible for counting the number of packets leaving the cluster.

Table 1 shows the relation of cluster / gateways to output CPUs. The column "Probability" is associated with the column "Output CPUs". Each probability is used to define the traffic management of each node according to a given application. These values also indicate the probability of a packet being serviced by the indicated output CPU. For example, the probability that cluster CLT_2 (which contains the cluster-head CPUs 3 and 4, Table 1) sends a packet from output CPU_3 to GW_1 is 1/3, and this probability is 2/3 for a transmission from output CPU_4 to GW_2.

Each mote receives packets at the input link and forwards them to one of the outbound links using UDP over IP (Datagram). If we assume that the arrival of requests for the RFID and AdHoc networks can be modeled as a Poisson process, the traffic volume of each individual mote can be extended to the traffic volume of a cluster by the simple sum of the rates of Poissonian arrivals. Thus, we sum the rates of each mote to form a cluster of ten motes.

The network configured in the following section - case study - is a network of low-capacity, low-cost and low-power devices (i.e motes) which has the capability to sense a parameter of interest. The sensed parameter is relayed to a mediator through the network formed amongst these nodes. Thus, the processing and transmission speeds are expected to be relatively low compared to traditional networks. Nevertheless, these features do not preclude the need for planning and dimensioning for the following reasons: 1) the number of devices can be quite large, which may amount to a correspondingly large traffic for a mediator; 2) an estimate of traffic allows the designer to determine the battery life of such system; 3) the capacity of the

Table 1: Network configuration.

Function	Probability	Output CPUs
GA_{12}	1	25
GA_{34}	1	28
GA_{57}	1	29,33
GA_8	1	19,34
AdHoc submodel	1,1,1,1	30,31,32,33
CLR_1	1	21
CLR_2	1	22
MD	1/2, 1/2	24, discard
GWI	1/3,1/3,1/3	23, 26, 27
GW_1	1	5
GW_2	1/3, 2/3	11,6
GW_3	1	14
GW_4	1	17
CLT_1	1/4, 3/4	1,2,20*
CLT_2	1/3, 2/3	3,4
CLT_3	1/2, 1/2	7,8
CLT_4	1/4, 3/4	12,15
CLT_5	1/3, 2/3	16,13
CLT_6	1/2, 1/2	9,10
CLT_7	1	18

* output-CPU 20 to GW_3 is used only in an emergency

links must be determined to allow for an efficient use of the channel. Furthermore, the proposed model is general and scalable, i.e. it is not restricted to this class of networks, and thus higher-capacity networks with a larger number of devices may also be analyzed through this model. All connections are assumed to be wireless. However, the model does not restrict the use of wired connections.

4 CASE STUDY

To evaluate each cluster independently, a MATLAB routine generates random positions for the ten motes within the cluster, every one second (in our case). This case used the Random Waypoint Mobility Model (RWP) to simulate the performance of the network. By changing different parameters, we can either increase or decrease the connectivity. For example, it is possible to increment the connectivity by increasing 1) the number of motes, or 2) the number of gateways (interconnection), or 3) transmission power or else 4) by decreasing the simulation area, or a combination of these factors. Mobility determines the location of each mote that selects a random destination and travels towards it in a straight line at a randomly chosen uniform speed.

The AdHoc network is spread over a 1000 x 1000 m^2 area. Each cluster consists of ten mobile motes and one or more static cluster-heads. For the “crossover” distance, $d_{crossover}$, there is a threshold ($d > d_{crossover}$) for which the “two-ray” propagation model is more adequate than the “free space” one, and $d_{crossover} = (4\pi h_t h_r)/\lambda$ = 547 m (Sommer, Joerer, and Dressler 2012).

The input parameters were the same from (Leite, Ursini, and Martins 2017), but with three values for transmission power (i.e. two additional values), 5, 10 and 15 dBm. Two basic propagation models (FS =

Free Space and TR = Two-Ray ground propagation model) were considered, which are described by the following equations:

$$P_{r,FS} = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}; \;\; d = \sqrt{\frac{P_t G_t G_r \lambda^2}{(4\pi)^2 P_{r,FS} L}} \tag{1}$$

$$P_{r,TR} = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4 L}; \;\; d = \left(\frac{P_t G_t G_r h_t^2 h_r^2}{P_{r,TR} L}\right)^{1/4}, \tag{2}$$

where P_r is the "receiver threshold". Considering 15 dBm (31.6 mW) of transmission power, a 582 m range (distance) is calculated for the "free space" and 564 m for the "two-ray" model. The conservative value of 500 m was chosen. These values are approximated, since we only considered the power that radiates up to the center of a transmitter, as shown in Fig. 2. The case where the power is not enough to reach the center of an adjacent mote was regarded as a lack of signal (for the sake of using motes without connectivity in the discrete-event simulation model). There may or may not be connectivity between these motes. Another interpretation is that the transmitted power is under the minimum dBm value (i.e. 5,10,15).

The remaining values were calculated (under the same assumption) using the "free space" propagation model as they show a distance of less than 500 m. For 10 dBm (10 mW), d = 327 m, and the value adopted was 300 m; for 5 dBm (3.16 mW), d = 184 m, and the value was set to 170 m. For instance, the probability of no connection P_f (for 15 dBm) can be calculated as:

$$P_f = 1 - (15 \times 10 + 2 \times 9 + 2 \times 8 + 1 \times 7)/200 = 1 - 191/200 = 0.045\ (4.5\%). \tag{3}$$

meaning that in 15 transmission attempts we had 10 motes with successful transmission; in 2 attempts we had 9 motes with successful transmission (and so forth), i.e. we had nine unsuccessful transmissions within 200 possible transmissions (20 simulated transmissions $\times$ 10 motes), thus resulting 0.045 or 4.5%. The P_f value was used in the discrete event simulation model to represent the "Disconnected State" for sensor nodes (AdHoc subnet), or the probability of lost connection. The same criterion was used to obtain 5 and 10 dBm loss values. The adopted mobility model is the one presented by Leite et al. (Table 2) (Leite, Ursini, and Martins 2017). The signal loss was 87.5 % for 5 dBm; 10.5% for 10 dBm and 4.95% loss signal for 15 dBm. Due to the fact that 87.5% (5 dBm) of signal loss is not acceptable from a pragmatic viewpoint, we ran the simulation with 20.5% and 49.5% of blocking. These values correspond to the transmission power, P_t, $5\ dBm < P_t < 10\ dBm$ (Figs. 2 and 3). The queuing delays and processor utilization for these connectivity loss values (i.e. blocking) are shown in Fig. 4 for an uncongested network.

5 RESULTS AND DISCUSSION

The most important result of this work is the analysis and estimation of the total traffic in the network of clusters considering the effect of mobility and fading, i.e. the traffic volume under dynamic conditions. We considered three scenarios, which are described as follows:

- *First Scenario - Overloaded Mediator*: In the first scenario, the inter-arrival times for a cluster are EXPO(0.6), i.e. one packet each 0.6 secs; thus the arrival rate is 1/0.6 = 1.67 packets/s (10 motes $\times$ 0.167 packets/s per mote). We used the service rate of 10 packets/s (i.e. 1/0.1), including the mediator. As we shall see in the next paragraphs, these values cause instability in the mediator since its utilization rate approaches 100%;
- *Second Scenario - Mediator with Extended Capacity:* In the second scenario, the inter-arrival times for a cluster are EXPO(0.6), i.e. one packet each 0.6 secs (the arrival rate is 1/0.6=1.67 packets/s, i.e. 10 motes $\times$ 0.167 packets/s per mote). We used the service rate of 1/0.02, meaning that the

Table 2: MATLAB input parameters

Input Parameters	Values
Receiver Threshold	-88 dBm
Area size	1000 x 1000 m^2
Antenna type	Omnidirectional
Antenna height (h_t, h_r)	1.5 m
Antenna gain (G_t, G_r)	1.0
System Loss Coefficient (L)	1.0
# Mobile nodes in a Cluster	10
Mobility model	Random Waypoint
Speed interval	[0.2 - 2.2] m/s
Pause interval	[0-1] s
Walk interval (walk time)	[2-6] s
Direction interval	[-180 + 180] degrees
Transmission frequency	5.8 GHz
Transmission power (P_t)	5, 10 and 15 dBm
Simulation time	306 s

service rate is 50, i.e. fifty packets are processed each second (a five-fold speed increase in relation to the first scenario). The increase in the service rate in the mediator (output-CPU-24) was enough to stabilize the system. Therefore, the stable network caused the emergency link from cluster CLT_1 (output-CPU-20) to the gateway (output-CPU-14) to remain mostly inactive, i.e. only a few packets flowed through it. Recall also that in the actual system, the processing delay is different for each network element. The results that summarize the dimensioning of the mediator are shown in Table 6;

- *Third Scenario - Simulation Validation - System without Mobility*. In this scenario, we validate our simulation model with a Jackson's queuing network model. Notice that we removed mote mobility from the AdHoc network, thus ensuring 100% connectivity so that we could validate the model. This is due to the fact that the adopted analytical model does not accommodate packet losses and mobility. Nevertheless, this assumption does not compromise the validity of the results. The Jackson's network analytical model (Jackson 1957) was calculated as a Markov process to validate the simulation model under the exponential distribution for both arrival and service distributions. However, once validated, it was possible to evaluate other conditions not allowed by the analytical model, such as different distributions other than the exponential, the inclusion of the loss of connectivity, and the probability distributions regarding the traffic between clusters.
  The packet arrival rate in each cluster is 1/0.6 = 1.67 packets/s. The first seven arrivals, each generated by a cluster CLT yield 1.67 packets/s (the remaining four are gateway inputs). The four gateways GW do not generate traffic. The two RFID clusters (CLR) also generate 1.67 packets/s; the mediator generates 5.0 packets/s due to its SNMP function. This amounts to 14 clusters as shown in Fig. 1.
  Therefore, the fresh arrival rates are: Γ = [1.67, 1.67, 1.67, 1.67, 1.67, 1.67, 1.67, 0, 0, 0, 0,1.67,1.67, 5.0]. We also need the 14 x 14 matrix R (Table 3), which describes the probabilities shown in Fig. 1 . The resulting total arrival rates in each cluster or gateway is given by the vector: $\lambda = \Gamma\,[I-R]^{-1}$, λ = [1.67, 3.54, 2.92, 1.67, 3.54, 2.92, 5.49, 4.68, 10.49, 0, 6.67,1.67,1.67, 20]. From the rates obtained (Table 4), it is possible to calculate the mean queue delays for each CPU (Table 5) (W_i, [i=1....24])

Table 3: Part of R Matrix: probability of transmission per output link of CPU - (CPU; Probability)

——	CLT1	CLT2	CLT3	···	GW1	GW2	CLR1	···	MD
CLT1	0	1; 1/4	2; 3/4	···	0	0	0	···	0
CLT2	0	0	0	···	3; 1/3	4; 2/3	0	···	0
CLT3	0	7; 1/2	0	···	0	8; 1/2	0	···	0
···	···	···	···	···	···	···	···	···	···
GW1	0	0	0	···	0	0	0	···	5; 1.0
GW2	0	0	0	···	11; 1/3	0	0	···	6; 2/3
CLR1	0	0	0	···	0	0	0	···	21; 1.0
···	···	···	···	···	···	···	···	···	···
MD	0	0	0	···	0	0	0	···	0

CLT - cluster, GW - gateway, CLR - Cluster RFID, MD - mediator

Table 4: Fresh arrival (Γ) and resulting arrival (λ) per cluster (packets/s) for the network

—	CLT1	CLT2	CLT3	···	GW1	GW2	CLR1	···	MD
Γ	1.67	1.67	1.67	···	0	0	1.67	···	5.0
λ	1.67	3.54	2.92	···	4.68	10.49	1.67	···	20

Table 5: Mean queue waiting time for some network CPUs: simulation (W_s) vs. analytical (W_a) results (*ms*).

—	CPU ID													
Time	1	2	···	8	···	11	12	13	14	···	18	···	23	24
W_a	4.4	14.3	···	17.1	···	53.8	4.4	30.9	–	···	121.7	···	–	5.0
W_s	4.9	14.8	···	17.6	···	58.3	4.5	32.2	–	···	131.1	···	–	5.6

CPU 19 - RESERVED (for future extensions).
CPUs 14 and 20: Emergency (not activated in this case study).
CPUs 23,25-34: Application CPUs, not contemplated in this example.
CPU 24: Mediator.

Table 6: Results for the mediator (CPU 24)

Parameter	First Scenario (overloaded mediator)	Second Scenario (extended mediator)
arrival rate (packets/s)	20	20
service rate (packets/s)	10	50
mean-queue-time (s)	79	0.0056
CPU 24 Util. (%)	100	20

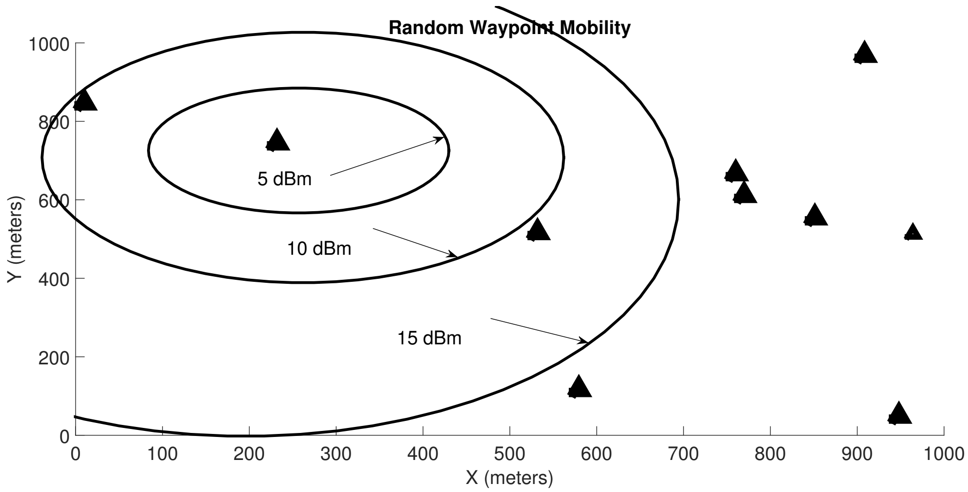

Figure 2: Power range for 5, 10 and 15 dBm (ten mobile motes).

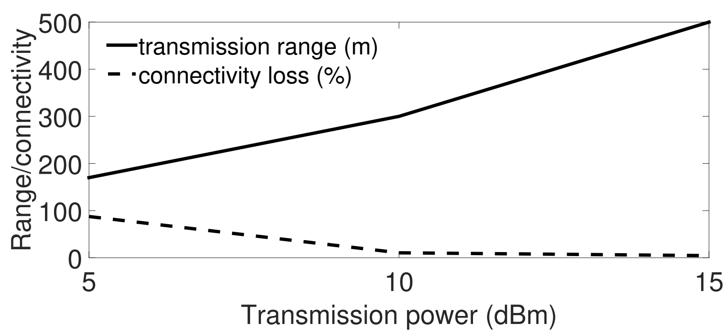

Figure 3: Connectivity and distance as a function of power range.

by means of the equation (4), which gives the delay in an M/M/1 queue:

$$W_i = \frac{\lambda_i/\mu_i}{\mu_i - \lambda_i}, \quad \mu_i = \frac{1}{0.1} = 10 \tag{4}$$

packets/s, where λ_i and μ_i are the arrival and service rates for each CPU; the exception is CPU 24, the mediator, which has a service rate of 50 packet/s in the second scenario. Since all the delay values obtained from the simulation model matched the ones from the analytical model (the largest error recorded is within a 10% limit), the simulation model may be deemed validated. This validation is a crucial step since it allows further extensions to this model, i.e. the inclusion of other model features such as new types of distributions.

We may observe in Table 6 that the mediator (output CPU-24) was overloaded in the first scenario ($\geq$ 100% utilization), which caused the entire network to delay packet processing. By increasing its service rate up to five times, the utilization dropped down to 20%, and the overall latencies also (globally) reduced.

The mean network delay $\overline{W}$ is given by equation (5), using both analytic and simulated CPU-i delay W_i, as follows (Table 5):

$$\overline{W} = \frac{\sum \lambda_i}{\sum \Gamma_i} W_i \quad , \quad i = [1...24] \tag{5}$$

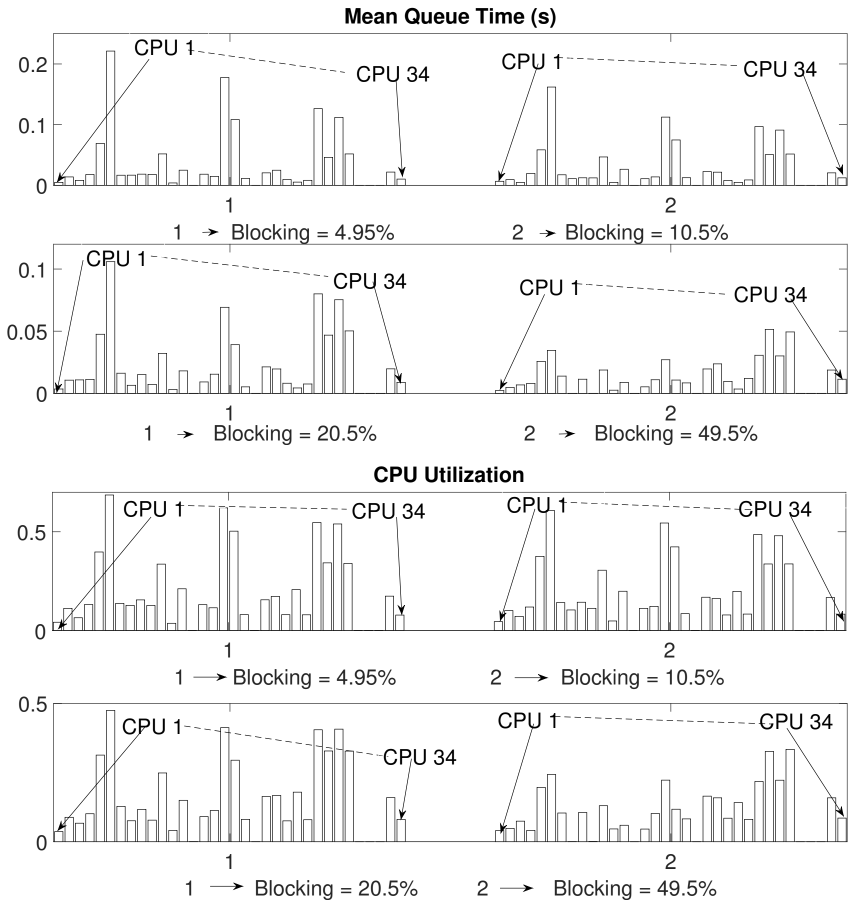

Figure 4: CPU mean queuing time (top) and utilization (bottom): connectivity loss (blocking) of 4.95%, 10.5%, 20.5% and 49.5% from left to right.

For the analytical model, we obtain $\overline{W_a} = 233.2$ ms, and for the simulation model $\overline{W_s} = 247.3$ ms.

The initial distribution adopted for the arrival and service rate was the exponential. This distribution is suitable since 1) it allows the validation of the model with an analytical model; and 2) it is the one that stresses the network (the worst case when there are no bursts). If the exponential distribution does not match the reality, it is possible to combine exponential distributions to form Erlang(k) distributions, which may better reflect the actual traffic model in the network. The infinite summation of Erlang(k) distributions leads to a constant distribution. Otherwise, if there are bursts in the network, the Pareto or Hyper-exponential distributions may be employed, depending upon the application. Once the model is validated by incremental evolution (Ursini, Timóteo, Santos, and Martins 2014), other types of extensions may be studied. Notice that the validation of the network was carried out in the third scenario because in the first scenario the mediator was found to be congested.

The second scenario corrected this condition and the third scenario validated the model, by adding the constraints of null mobility and full connectivity. The numerical results of the simulation can be made more precise (i.e. closer to the values from the analytical model) by adjusting a number of factors, e.g. both the number of simulation runs and also the size of the simulation duration. The proposed model is general and it can be instantiated for specific applications. For example, the probabilities of transmission for outgoing links can be measured in a real application and replaced in the model. The arrival- and service-time distributions considered may also be replaced by actual measurements and/or other types distributions.

6 CONCLUSIONS

The performance of IoT networks is largely dependent upon the capacity of the mediator since it is a traffic concentrator. To specify its capacity, one must resort to simulation and analysis of the traffic generated by the plethora of technologies covered by the IoT networks.

In this work, we have tackled the issue of dimensioning the capacity of the mediator, by considering distinct types of traffic and the diversity of devices that may compose the system. To model the effects of mote mobility, the Random Waypoint algorithm was used to complement the discrete event simulation. This model captured a number of features of complex systems, including the mediator, gateways, emergency nodes, Internet and IoT traffic, and most important the traffic generated by RFID tags and sensors. We analyzed through a case study the mean queuing time and the output-CPU utilization for each cluster for a given probability of connectivity of motes resulting from their mobility. Through the model, it was possible to estimate the incoming and outgoing traffic for each cluster and the IoT mediator, which was the focal point and the initial goal of this work.

In future work, we would like to enhance the model with a traffic growth prediction model, which will allow a more precise estimation of the spare capacity that should be considered in the design of the mediator. Furthermore, the mobility model used in this work assumed for illustration purposes a lower mobility of the devices. We also contemplate exploring this issue by increasing the mobility of the notes in the network to a point that it models a VANET.

The model that was presented is scalable, meaning that it accommodates the inclusion of other types and number of components, by using the concept of clusters. Therefore, we argue that it may provide a useful tool for dimensioning devices within other applications, including the context of smart cities. In a real case, the features of each real network have to be incorporated in the simulation model. For example, the packet size and the link rate must be considered variable. The model presented is flexible because it allows for such adaptations.

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