Modeling and Analysis of End-To-End Delay for Ad Hoc Pervasive Multimedia Network

Kamal Kumar Sharma, Hemant Sharma and A. K. Ramani

***Abstract*— A primary challenge in mobile ad hoc network scenario is the dynamic differentiation of provided levels of Quality of Service (QoS) depending on client characteristics and current resource availability. In this context the paper focuses on characterizing the average end-to-end delay and maximum achievable per-node throughput for In-vehicle ad hoc multimedia network with stationary and mobile nodes. This work considers an approximation for the expected end-to-end packet delay based on the assumption that the traffic at each link acts as an independent M/D/1 queue.**

The paper establishes the network model and delay model for ad hoc multimedia network. It further presents analysis and evaluation of the delay model based on an experimental multimedia communication scenario.

***Index Terms*— Ad Hoc Networks, In Vehicle Multimedia, Bluetooth, Delay Analysis.**

I. INTRODUCTION

The automobile industry has seen a shift towards the use of more on-board technology and, is becoming increasingly software-dependant. From sophisticated navigation systems to computer-controlled driver assistance safety systems and *in-car multimedia and entertainment*, the amount of software written for cars is increasing rapidly. Further, the proliferation of multimedia capable mobile devices, such as novel multimedia enabled smart phones, has encouraged users inside a vehicle to consume multimedia content and services, while on move. This has provided a possibility to share the data contents among smart phones and the devices inside the car, such as infotainment systems or rear-seat entertainment systems, by establishing an *Ad hoc* network.

Ad hoc networking offers wireless communication without any administrative overhead. To facilitate communication between devices far away from each other over several hops the network has to include so-called forwarding nodes. Available technologies for ad hoc networking are the widespread IEEE 802.11 and the Bluetooth [1] technology. It has been widely predicted that Bluetooth will be the major technology for short range wireless networks and wireless personal area networks in automotive domain. Bluetooth ad-hoc networking also presents new technical challenges, such as scheduling, network forming and routing.

With the growing demand for real-time applications over wireless networks, increasing attention is paid to the delay analysis of transmissions over error-prone channels. In multihop networks, like ad hoc, mesh, and multihop cellular networks, the analysis is more challenging than in single-hop networks due to the delay accumulation at each hop. Many factors affect the end-to-end delay, including the routing algorithm, the MAC and packet scheduling algorithm and error-prone wireless channels. The analysis is unlikely to be tractable if all these factors are considered together.

This paper presents an approximation for the expected end-to-end packet delay based on the assumption that the traffic at each link in the network acts as an independent M/D/1 queue [12]. A queuing model for traffic is used for wired networks [13] and is applicable to a wireless network by accounting for operation of the hardware in half-duplex mode. The approximation can be applied for a known fixed routing and a conflict-free schedule defined by a repeating frame of equally-sized time slots. This represents the state of an ad hoc multimedia network at the time of route and schedule updates, and the performance may change as node(s) change positions.

The rest of the paper is organized as follows: Section 2 provides an overview of In-car ad hoc multimedia network architecture and presents its system model. Section 3 describes the experimental set-up and experimental scenario to analyse the system model. In section 4, we evaluate the delay model of the network. Section 5 provides an overview of related research. Finally, Section 6 concludes the paper.

II. IN-VEHICLE AD HOC MULTIMEDIA NETWORK

The network organizes *infotainment application contents* into communication channels to facilitate identification and the communication of intended data streams. Therefore, every application subscribes to the channels that it is interested in, and his corresponding device node will try to retrieve any contents belonging to those channels. The framework follows the approach used in Internet-based podcasting protocols and structures channels into different media streams.

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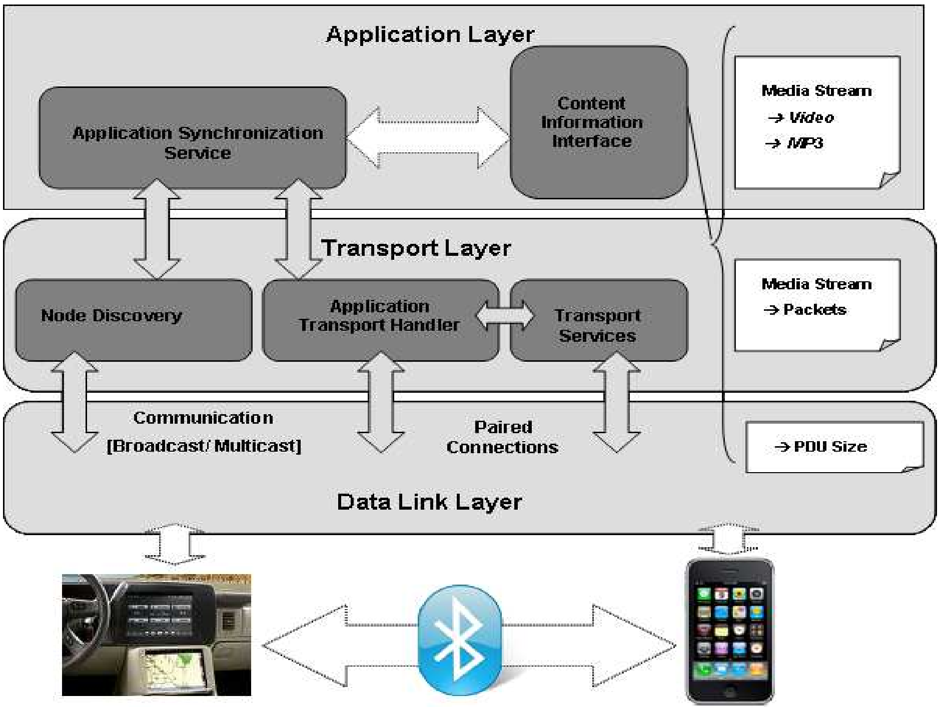

Figure 1: Overview of Ad Hoc Multimedia Network Architecture

To make efficient use of contacts with a small duration, the streams are further divided into data packets, transport-level data units of a size that can typically be downloaded in an individual node encounter. The data packets are further organized into protocol data units (PDU), the atomic transport unit of the network.

A. System Overview

The system architecture for *ad hoc multimedia network* is illustrated in Figure 1. The transport layer acts directly on top of the link-layer without any routing layer. To distribute contents among the communicating nodes, the framework does not rely on any explicit multi-hop routing scheme. Instead of explicitly routing the data through specific nodes, it relies on a receiver-driven application-level dissemination model, where contents are routed implicitly as nodes retrieve contents that they request from neighboring nodes. It distinguishes between an application layer, a transport layer, and the data link layer. In a first level of aggregation, the applications organize their data contents in media stream channels.

Below the application layer, the transport layer organizes the data into data streams. Streams are smaller data units that should be able to communicate over short contacts. The use of smaller file blocks is also supported by the idea of integrating forward error correction, for instance the use of fountain codes, to speed up and secure the data transfer, specifically when packets are received unordered. The streams packets themselves are then again cut into smaller parts to optimize the interaction with the data link layer; i.e., the size is set to the PDU size of the data link layer.

The proposed system is designed to work on any MAC architecture, however, to be effective even in the presence of short contact durations, short setup times and high data rates are important for achieving high application communication throughput.

B. Application Scenarios

The ad hoc multimedia network consisting of Infotainment system and the slave devices shall provide following services:

- Access to audio contents from *iPhone* to *In-car Infotainment system* that could be played and hearable on the vehicle’s sound system.
- Access to video contents from *iPhone* to *Rear- seat entertainment unit* via the *piconet* master.
- Access to internet from *Rear-seat unit* using *iPhone* via the *piconet* master.
- Applications based on Information contents received by the *iPhone* to help safe driving, such as weather information or traffic information.

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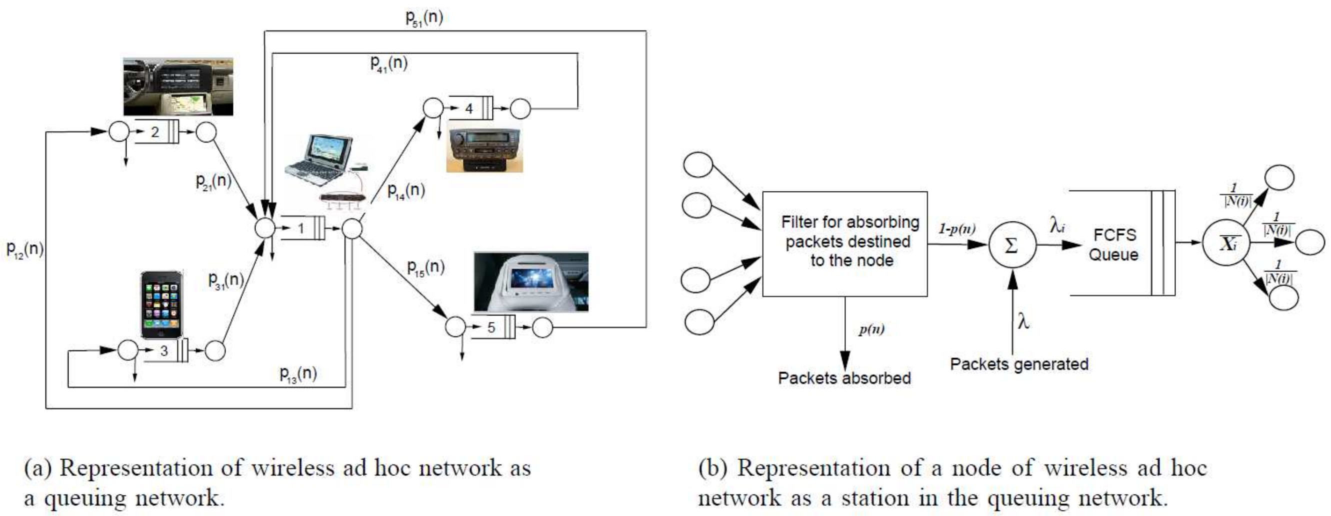

Figure 2: Network Model for Ad Hoc Multimedia Network

C. Network Model

The model considered here is that of a wireless ad hoc network with nodes assumed either fixed or mobile. The network consists of a normalized unit area torus containing n nodes [9]. For the case of fixed nodes, the position of node i is given by Xi. A node i is capable of transmitting at a given transmission rate of W bits/s to j if [10],

$$|X_k - X_j| \geqslant (1+\Delta)|X_i - X_j|,$$

Where $\Delta > 0$, such that the node X_k will not impede X_i and X_j communication. This is called the protocol model [10].

For the case of mobile nodes, the position of node i at any time is now a function of time. A successful transmission between nodes i and j is governed again by above equation, where the positions of the nodes are time dependent [9]. Time is slotted to simplify the analysis. Also, at each time step, a scheduler decides which nodes are sources, relays, or destinations, in such a manner that the association pair (source–destination) does not change with time.

The multimedia network presented in previous section resembles to multihop wireless ad hoc network, and therefore, can be modeled as a queuing network as shown in Figure 2(a). The stations of the queuing network correspond to the nodes of the wireless network. The forwarding probabilities in the queuing network, denoted by p_{ij}, correspond to the probability that a packet that is transmitted by node *i* enters the queue of node *j*. Figure 2(b) shows a representation of a node in the ad hoc network as a station in the queuing network.

The end-to-end delay in a wireless network equals the sum of queuing and transmission delays at source and intermediate nodes. We will use the queuing network model shown in Figures 2(a) and 2(b) in order to mathematically analyze the end-to-end delay.

D. Delay Model

The end-to-end packet delay allows for evaluation of the quality of service (QoS) under low, moderate, and high traffic [10]. For this discussion the following assumptions are needed.

- The external traffic source attached to each node generates Poisson distributed packet arrivals with average traffic load λ/N (packets/slot) where N is the number of nodes in the network, and λ is the total external traffic load.
- Packet destination is equally likely among nodes.

The initial source (S) and final destination (D) of a packet is denoted by an (S, D) pair. In a multihop ad-hoc network a routing algorithm must be used to select a set of intermediate links (path) between (S, D) pairs to route the packet. Therefore, the average traffic load passing through a link (i, j), λ_{ij}, is the result of external and internal traffic [10].

$$\lambda_{ij} = \sum_{\substack{\forall (S,D) \text{ routed} \\ \text{through link } (i,j)}} \frac{\lambda}{N(N-1)} = \frac{\lambda}{N(N-1)} T_{ij} \qquad (1)$$

Here Tij are the elements of the relative traffic load matrix T given by the cardinality of the set of *(S;D)* pairs routed through link (i; j). In other words, Tij represents the number of route paths that traverse link (i; j). The assumption of *poisson arrivals* to a node does not represent bursty traffic or capture the effects of relayed packets through a slotted-time system, but it is used in [12], in the approximation here, and in other studies of ad-hoc networks due to its simplicity, ease of analysis, and reproducibility of the results it provides.

A randomly selected packet transmitted from node S to node D experiences a random delay D_{SD} that is the sum of the delays on every link traversed in the selected path. Averaging over all the

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equally likely *(S;D)* pairs in the network, the expected end-to-end delay is given by

$$E[D] = \frac{1}{N(N-1)} \sum_{\forall (S,D)} \sum_{\substack{\forall \text{ link } (i,j) \text{ in path} \\ \text{selected to route } (S,D)}} E[D_{ij}] \ . \qquad (2)$$

E[Dij] is the expected packet delay over link (i; j) and is a function of the external traffic load, internal traffic load, medium access control (MAC) protocol, and the multiple access interference (MAI). An exact analysis for E[Dij] in the wireless scenario appears to be very difficult [19]. Nevertheless, the above equation can be rewritten in terms of the relative traffic load.

$$E[D] = \sum_{\substack{\forall \text{links}(i,j) \\ \text{in the network}}} \frac{T_{ij}}{N(N-1)} E[D_{ij}] \qquad (3)$$

Since coordination among nodes exists, it is possible to estimate the relative link capacity assigned to each link after creating the link schedule. Through the scheduling algorithm the number of slots assigned to a link is more or less controlled.

However, in general, the resulting number of slots assigned to a link depends on several factors including the topology and location of a particular node. For instance, links at the network edge will be subject to less MAI than those at the center of the network.

In addition, nodes at the center of the network may carry higher relative traffic. Nevertheless, the capacity assigned to a given link (i; j) after creating the schedule can be computed. Let n_{ij} be the number of slots within a period of the schedule, N_f , allocated to link *(i; j)*; then the relative link capacity C_{ij} is given by (4).

$$C_{ij} = \frac{n_{ij}}{N_f} \ . \qquad (4)$$

In order to estimate $E[D_{ij}]$ the following assumptions are needed:

- Each node uses a different infinite length buffer for every feasible outgoing link.
- Packet arrival times to be transmitted over each link are Poisson distributed with arrival rate λ_{ij} given by (1).
- The n_{ij} slots assigned to link (i; j) are uniformly distributed within the schedule.
- Packet reception is error free.

If these assumptions are used, the expected packet delay through link (i, j), $E[D_{ij}]$ can be modeled as the resulting packet delay in a TDMA system (M/D/1 queuing model) with a frame length N_f/n_{ij} and packet transmission time of 1 slot [20]. Hence, (3) can be approximated by (5).

$$E[D] \approx \hat{D} = \sum_{\forall \text{ link } (i,j)} \frac{\lambda_{ij}}{\lambda} \left[\frac{1}{2(C_{ij} - \lambda_{ij})} + 1 \right] \quad \text{slots} \ . \qquad (5)$$

In the next section, the analysis of this delay model has been presented.

III. Model Analysis

A. Experimental Setup

In order to investigate the performance of the approximation in equation (5), a Bluetooth simulator program, *BT-Sim* [18] is used on a laptop. The laptop had been paired with iPhone and Infotainment System to form an ad hoc network. In the simulator, external packets arriving at each node are generated according to a Poisson process using the procedure described in [9]. Poisson arrivals and destination node are generated using a linear congruential pseudorandom number generator. Simulation of equally likely packet destinations is done following the recommendation given in [10]. The statistical properties of these processes have been verified to ensure that the random generator works well for the number of packets generated in the network.

According to [21], this improves credibility of the results. First-In-First-Out (FIFO) buffers of length 500 packets are used for each outgoing link where packets were placed after their reception to be forwarded using information from the routing table. The simulation is executed until each node transmits 1000 packets to every other node in the network. This is repeated and the measured delays are averaged until the 95% confidence interval lies within 0.1% of the average. This stop criterion has been adopted from [20].

B. Experimental Scenario

All links in the network are first numbered according to traffic load so that heavily loaded links are given higher priority in access to the channel. Sets of non-interfering links are then constructed by attempting to add links in order of priority. Through this process, the following assumptions are used.

- A node can either transmit or receive a single packet in a given slot.
- The channel can be spatially reused. Links located two hops apart produce negligible interference.

All links are assumed to be of the same quality and the network is represented by a connected graph. Once the schedule is generated, slot assignments are scrambled in an effort to distribute link access to the channel uniformly within the frame.

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The expected delay given by the approximation is denoted Ď while the average value provided by the simulation is denoted Đ, both of which are functions of the total external arrival rate λ. The maximum throughput λ^* is the maximum value of λ for which Ď remains finite. The approximation error is defined as

$$\xi = (Ď - Đ) / Đ \qquad (6)$$

These values are expressed as a percentage, and positive values of ξ indicate that the approximation overestimates delay. For performance comparisons, values of ξ are found for the low traffic load $\lambda = 0.10\lambda^*$ and a high traffic load $\lambda = 0.75\lambda^*$. These errors are denoted ξ_{low} and ξ_{high}.

IV. Model Evaluation

The end-to-end delay versus offered traffic is shown for the network based on *tandem topology* in Fig. 3. The approximation follows the trend in the simulated throughput-delay over all traffic loads. It tends to underestimate delay at low traffic loads for the topology considered. At high loads, the approximation provides a clear overestimate for tandem networks Though caution should always be taken in applying an approximation, the one examined here is clearly reasonable for the multimedia services considered and thus useful for quick evaluations.

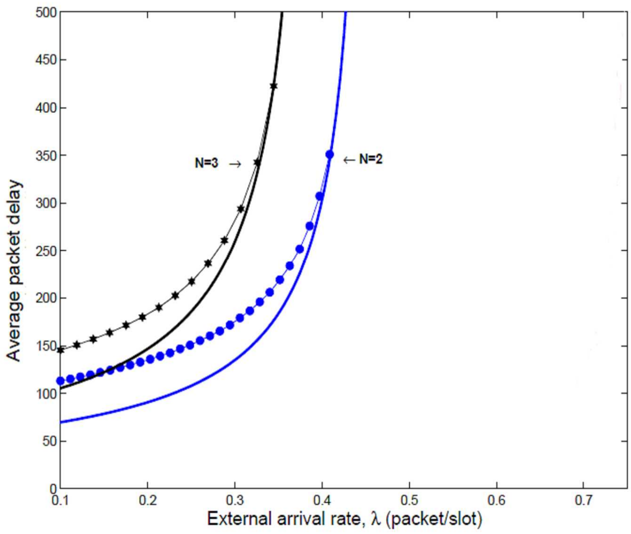

Figure 3: End-to-end Delay versus Offered Traffic

The degradation in performance of the approximation for high traffic load in a tandem network is clearly evident in figure 3. Simulation results have been verified to ensure that buffer overflows do not occur and that the simulated delay does asymptote as the external arrival rate approaches maximum throughput.

For a tandem network, this asymptote is quite sharp, but the approximation does not reflect such sharpness. In the tandem networks, it appears from the figure that the approximation gets worse as network size increases. A relatively high error was found for low traffic but the approximation error for high traffic loads is at most 11%.

However, the approximation improves with increasing traffic load, and the poor performance at low loads is in stark contrast to its convergence with simulated results at maximum throughput. These results are most extendable to other cases. The performance of the approximation clearly depends on the network topology and size. These two parameters influence traffic and directly affect the packet arrival process to the queue of each link which, together with the uniform slot assignment distribution, is a key assumption of the model. In the case of tandem network, the arrival process to each link appears to be renewed by packets entering and leaving the network, and the *poisson assumption* for the process is reasonable.

V. Related Research

Bluetooth is a low-cost technology initially designed for cable replacement [2] but more generally intended for all kinds of Personal Area Network (PAN) applications [3]. It is probable that, in the very near future, Bluetooth will be embedded in almost every mobile device. These features coupled with the interoperability characteristic provided by Bluetooth specifications [1], make this wireless technology very appealing for applications in automotive environments [4]. As an example, Bluetooth headsets are very popular as wireless audio link to a mobile phone, also for vehicular use. These reasons make Bluetooth the most suited technology for the design of the low power Wireless Communication Network (WCN).

The issue of performance management for multimedia distribution network has been faced at different levels of abstraction. At lower layers of the OSI protocol stack, several important research activities have introduced QoS-aware protocols for resource reservation, service differentiation, traffic engineering, and constraint-based routing [14, 15]. At a higher layer of abstraction, a wide spectrum of research activities, from both industry and academia, has investigated middleware solutions for multimedia performance management. For instance, content distribution networks exploit statically installed or self-organizing decentralized infrastructures to cache traversing flows and to transparently balance the request load by considering client locations [16, 17].

Several studies have focused on finding the maximum achievable throughput and characterizing capacity-delay tradeoffs in wireless ad hoc networks [8-13].

In [5], the authors characterize the delay-throughput tradeoffs in wireless networks with stationary and mobile nodes. It is shown that for a network with stationary nodes, the average

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delay and throughput are related by $D(n) = \Phi(nT(n))$, where D(n) and T(n) are the average end-to-end delay and throughput respectively. In [8], the authors use simulations in order to study the dependence of per-node capacity on IEEE 802.11 MAC interactions and traffic pattern for various topologies like single cell, chain, uniform lattice and random network.

Several recent studies have proposed queuing models for performance evaluation of the IEEE 802.11 MAC. A queuing model for performance evaluation of IEEE 802.11 MAC based WLAN in the presence of HTTP traffic is proposed in [9]. In [10] the service time of a node, in IEEE 802.11 MAC based wireless ad hoc network, is modeled as a Markov modulated general arrival process. A finite queuing model is proposed and used in [13] for evaluating the packet blocking probability and MAC queuing delays in a Basic Service Set with N nodes.

In [11], the authors use queuing theoretic approach in order to calculate the mean packet delay, maximum throughput and collision probability for an elementary four node network with hidden nodes and extend the results to linear wireless networks. An analytical model for evaluating closed form expression for the average queuing delay over a single hop in IEEE 802.11 based wireless networks is presented in [12].

VI. Conclusions

In the paper, the network model and delay model for ad hoc In-car multimedia network has been presented. In order to compute the expected end-to-end packet delay the relative traffic load, number of slots assigned to each link, and the schedule frame length are needed.

Computer simulation has been used to evaluate the delay approximation using this model for tandem topology. The results show that the approximation is most suited to a tandem network, where traffic acts in a similar fashion to that described by *Kleinrock's independence assumption* [19]. In this case, performance of the approximation is better at low traffic loads and deteriorates with increasing network size

This contribution shows that analytical approximation can be used for fast evaluation of *ad hoc network capacity and delay* in automotive environment

Evaluation of delay model in car environment is the first objective of our future work. We anticipate two main directions:

- The use of delay model to develop performance analysis tool(s).
- Delay performance analysis for different multimedia network services.

References

[1] Bluetooth Special Interest Group., "Core Specification of the Bluetooth System v 3.0". Apr. 2009.

[2] J.C. Haartsen, "The Bluetooth Radio System," IEEE Personal Comm., vol. 7, no. 1, pp. 28-36, Feb. 2000.

[3] P. Johansson, M. Kazantzidis, R. Kapoor, and M. Gerla, "Bluetooth: An Enabler for Personal Area Networking," IEEE Network, vol. 15, no. 5, pp. 28-37, Sept.-Oct. 2001.

[4] R. Nüsser, R. Pelz, "Bluetooth-based Wireless Connectivity in an Automotive Environment", Proc. of the IEEE Vehicular Technology Conference, Fall 2000, vol. 4, pp.1935-1942.

[5] A. K. Dey, D. Salber, and G. D. Abowd, "A conceptual framework and a toolkit for supporting the rapid prototyping of context-aware applications", Human-Computer Interaction, 16(2-4):97–166, 2001.

[6] A. Schmidt, K. A. Aidoo, A. Takaluoma, U. Tuomela, K. Van Laerhoven, and W. Van de Velde, "Advanced interaction in context". In 1st International Symposium on Handheld and Ubiquitous Computing, volume 1707 of Lecture Notes in Computer Science, pages 89–101. Springer, 1999.

[7] G. Chen and D. Kotz., "Context aggregation and dissemination in ubiquitous computing systems". In 4th IEEE Workshop on Mobile Computing Systems and Applications, Callicoon, June 2002.

[8] A. E. Gamal, J. Mammen, B. Prabhakar, and D. Shah. Throughput-delay trade-off in wireless networks. In Proceedings of IEEE INFOCOM (INFOCOM'04). IEEE, March 2004.

[9] P. Gupta and P. R. Kumar. Capacity of wireless networks. IEEE Trans. on Information Theory, pages 388–404, March 2000.

[10] J. Li, C. Blake, D. S. D. Couto, H. I. Lee, and R. Morris. Capacity of ad hoc wireless networks. In MobiCom '01: Proceedings of the 7th annual international conference on Mobile computing and networking, pages 61–69, New York, NY, USA, 2001. ACM Press.

[11] X. Lin and N. B. Sheroff. Advances in Pervasive Computing and Networking, chapter 2, pages 17–55. Springer Science, New York, NY, 2004.

[12] D. Miorandi, A. A. Kherani, and E. Altman. A queueing model for HTTP traffic over IEEE 802.11 WLANs. In Proceedings of 16th ITC Specialist Seminar on Performance Evaluation of Wireless and Mobile Systems, August 2004.

[13] M. Ozdemir and A. B. McDonald. An M/MMGI/1/K queuing model for IEEE 802.11 ad hoc networks. In Proceedings of the 1st ACM International Workshop on Performance Evaluation of Wireless Ad Hoc, Sensor, and Ubiquitous Networks, pages 107–111. ACM Press, 2004.

[14] X. Masip-Bruin, M. Yannuzzi, J. Domingo-Pascual, A. Fonte, M. Curado, E. Monteiro, F. Kuipers, P. Van Mieghem, S. Avallone, G. Ventre, P. Aranda-Guti´errez, M. Hollick, R. Steinmetz, L. Iannone, K. Salamatian, Research challenges in QoS routing, Computer Communications 29 (2006) 563–581.

[15] X. Zhou, J. Wei, C.-Z. Xu, Quality-of-service differentiation on the internet: A taxonomy, Journal of Network and Computer Applications 30 (1) (2007) 354–383.

[16] G. Peng, CDN: Content Distribution Network, Technical Report TR-125, Department of Computer Science, State University of New York, Stony Brook, 2003.

[17] A. Vakali, G. Pallis, Content Delivery Networks: Status and trends, IEEE Internet Computing 7 (6) (2003) 68–74.

[18] BT –Sim http://btsim.sourceforge.net/index.html.

[19] D. Bertsekas and R. Gallager, *Data Networks*, Prentice Hall International,2nd Edition, 1992, p.211.S. M. Ross, Simulation, Academic Press, 2nd Edition, 1997, p.119-120.

[20] S. M. Ross, *Simulation*, Academic Press, 2nd Edition, 1997, p.119-120.

[21] K. Pawlikowski, H-D. J. Jeong, and J-S. R. Lee, "On credibility of simulation studies of telecommunication networks," IEEE Communications Magazine, Vol.40 no.1, January 2002.

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