Performance Analysis of a MAC Protocol for Speech transmission in Optical Wireless Communications

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***Abstract*- Optical wireless systems and networks combine the advantages inherent in optical systems with the merits of wireless connectivity. There is a need to design and evaluate MAC protocols for this particular environment. This paper discusses the design of a MAC protocol design for speech transmission and evaluates its performance in wireless terminal-to-terminal scenarios. Analytic results are reported and a MAC protocol simulator is constructed and used to verify the results. The system performance in terms of throughput, packet access delay and pack dropping probability is evaluated showing good agreement between simulation and analytic results.**

1 INTRODUCTION

Recently mobile communications have taken huge leaps; the increase in availability, production and purchase of mobile phones and PDAs are evidence of this. The emergence of Optical Wireless Communication (OWC) [1-2] and more specifically infrared (IR) technology is a move towards in that direction. Infrared technology offers major performance advantages over traditional cable or radio systems, with huge achievable bit rates in excess of 1.5 Gbs [3]. Unlike radio and microwave technologies, infrared offers complete freedom from interference and radio licensing regulations. As extensive research continues in OWC, the requirement for a MAC protocol designed specifically for IR transmission has become essential. This paper discusses such a design, which provides mobile-to-mobile communication and evaluates system performance through simulation and analytical models.

2 REAL WORLD MODEL

The network structure envisaged for the proposed protocol is as shown in Figure 1 that illustrates the cellular network structure. Consider an example of a company building, every office may contain a number of cells, smaller rooms may only consist of one or two cells. Every node within a cell then transmits to a satellite point on the building ceiling using the infrared medium, by means of transceivers fitted to the mobile nodes. The satellites communicate with a base station, which corresponds with each satellite about the availability of slots on the respective protocol. The base stations are inter connected via optical fibre links, which provide the backbone of the network and allow the whole building to become interlinked. Each satellite consists of an array of LEDs or lasers, which satisfy the eye safety standard recommendations established by the International Electrotechnical Commission (IEC) [4]. Lasers have been deemed a safety hazard for indoor applications, as they are a point source emitter. Ways of extending or diffusing the laser source to comply with IEC825 are known [4]. To achieve maximum throughput, the rate at which a mobile node transmits should adapt according to its position within the cell.

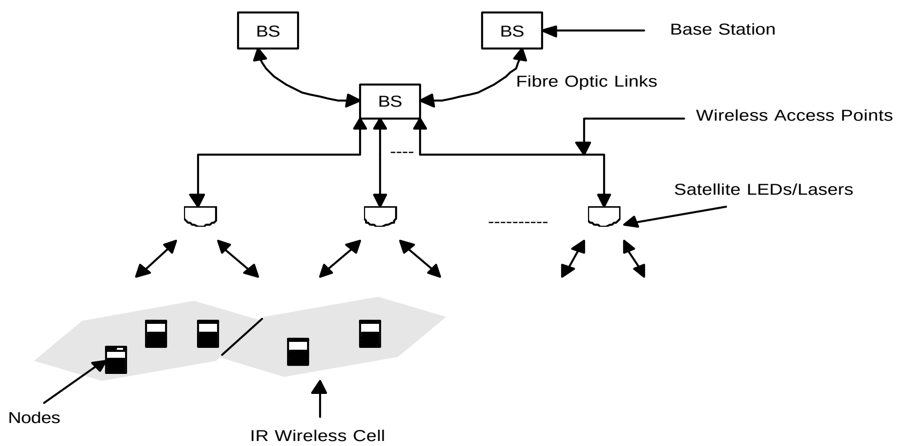

Figure 1: Optical Wireless Network Structure

3 DESIGN OF MAC PROTOCOL

The MAC Protocol is based on Packet Reservation Multiple Access (PRMA) [5], a terminal-to-terminal transmission protocol (through base station) for wireless local area networks. PRMA is a TDM based protocol, and uses CSMA/CA [6] techniques to avoid collisions when users try to reserve a slot.

The time organisation of Uplink and Downlink frame of the MAC protocol [7] can be seen in Fig 2. Each frame is divided in to J channel frames. The uplink frame consists of a reservation (R) slot and N information slots. The downlink frame consists of an acknowledgement (ACK) slot and N information slots. Node needs to reserve a slot before it actually transmits the data.

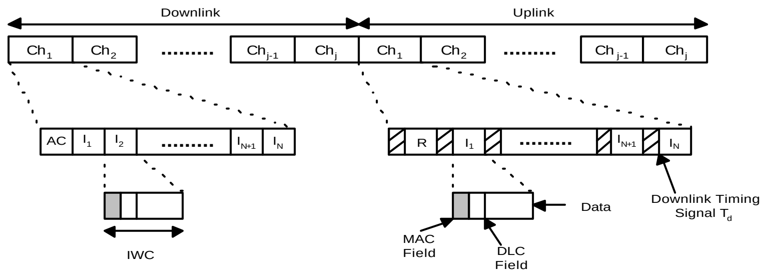

Figure 2: Timing Organisation of the MAC Protocol

The nodes request the reservation by transmitting their source and destination addresses through the R slot. The duration of the I slot is the transmission time of an infrared (IR) wireless cell. The base station uses the ACK slot to broadcast messages for each downlink slot as well as reservation messages for each node, which requested a slot. Nodes start to transmit in their own time slots by means of short downlink timing signals (T_d).

When an acknowledgement is received, the transmitting node will know which slot (in the uplink frame) is allocated to it, and the receiving node will identify the corresponding slot in the downlink frame from which it is to extract the data. The receiving node will continue to read data from this slot until it encounters an end of transmission (EOT) value, upon which the slot is released for contention.

If there are no free slots, when nodes try to reserve a slot, a delivery delay occurs for the packets waiting to be transmitted. For real time services like voice, this delay should not exceed a maximum delay of D_{max}. For speech, packet dropping probability at which speech quality degradation is indiscernible must be less than 1%. The MAC protocol allocates fixed number of slots in each channel frame.

4 THEORETICAL MODEL

To investigate the performance of this MAC protocol, a theoretical model was developed [8]. In this analysis, a finite number (M) of homogenous voice users are considered. Each user has a speech activity detector with talkspurts and silences that follow a negative exponential distribution. Talkspurt duration (t1) is equivalent to the message length or service time [11] and gap duration (t2) is equivalent to the interarrival time of messages.

The MAC protocol is designed so that the uplink channel frame rate is identical to the arrival rate of periodic (voice) packets. The analysis considers only the statistical allocation of the time slots. It also ignores the co-channel interference [10] and ISI in the physical layer by using a large channel re-use factor and a channel bit rate no greater than 10 Mb/s. The system performance depends on the packet arrival pattern and MAC structure. The packets arrival rate conforms to a Poisson distribution and so the inter-arrival times of the packets follow a negative exponential distribution. A mathematical model for MAC protocol under these features was designed as an $M/M/N/\infty/M$ queuing model consisting of exponentially distributed durations (M) of all talk spurts and gaps exponential service (M), N parallel servers, infinite storage and M users [9].

The number of time slots (servers) N per channel frame is given by

$$N = \mathrm{int}\left[\frac{R_C T_{cf}}{2JT_{cf}R_S + H}\right] \qquad (1)$$

where int [x] is the largest integer smaller than or equal to x, R_c is the channel bit rate, R_s is the source rate, H is the header of IWC and J is the channel reuse factor. T_{cf} is the channel frame duration and is given T_{cf} = (Tf/J)-(ACK/R_c), where T_f is the uplink/downlink frame duration. Transmission delays between nodes and satellite points are negligible. The number of voice users in the system at a given time, can be obtained by using birth-death theory for finite source queues.

5 SIMULATOR DESIGN

A simulator is designed to simulate the above-described MAC protocol. The simulator employs event driven simulation and is programmed in Java (2) using object-oriented concepts. As Java is a machine independent language, the simulator can be run on any operating system or platform/environment.

The simulator uses Poisson process to generate traffic for each node. Even though, statistically self-similar process generates better traffic as compared to Poisson process [12-13], Poisson models are still used to generate traffic for simulations because they can be modelled easier than self-similar processes [14]. Poisson models have another advantage; they can be defined by just a single parameter (in this paper, interarrival mean time). Using an inverse transformation, packet interarrivals are generated [15]. The simulation used about 40is done for millions of packets and the performance of the system in terms of throughput, access delay and packet dropping probability is evaluated.

6 PERFORMANCE ANALYSIS

In this section, we analyse the performance of the system using fixed number of voice sources. The performance for given system parameters depends on the packet arrival pattern and MAC structure. The system performance in terms of throughput, average access delay, and packet dropping probability is evaluated for a range of system parameters. Table 1 lists the system parameters used.

Variable	Notation	Value
Channel bit rate	R_c	10 Mb/s
Speech peak bit rate	R_s	64 kb/s
Uplink/downlink frame duration	T_f	3.1 ms
Downlink timing signal	T_d	4 bits
Speech mean ON duration	t_1	1 s
Speech mean OFF duration	t_2	1.35 s
Speech maximum time delay	D_{max}	20 ms
Channel reuse factor	J	7
Size of an IWC	H	53 bytes

Table 1: System Parameters

System Throughput is one of the important measures of system performance. Figure 3 shows the throughput (T) against M, throughput increases gradually with M as more of the channel rate becomes utilised. This reaches a saturation point at which throughput can no longer increase even though the numbers of nodes are increasing. As it can be seen from Figure 3, the throughput for the simulated system is compared to the theoretical model, which shows good correlation between both of them and indicates good system stability.

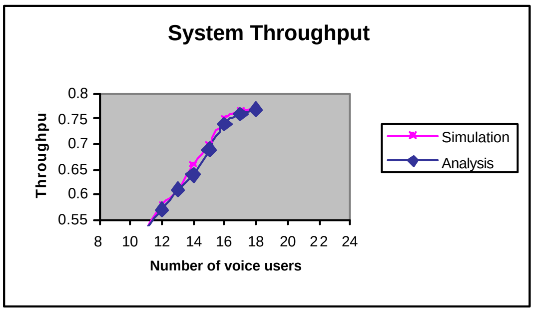

Figure 3: System Throughput vs. Voice Nodes

The transmission delay considers all packets transmitted from a source node to its destination node and the subsequent delay incurred. Figure 4 illustrates the transmission delay of the system, which increases significantly after M exceeds 10 due to the wait and contention of available slots. The theoretical results agree with the simulated results.

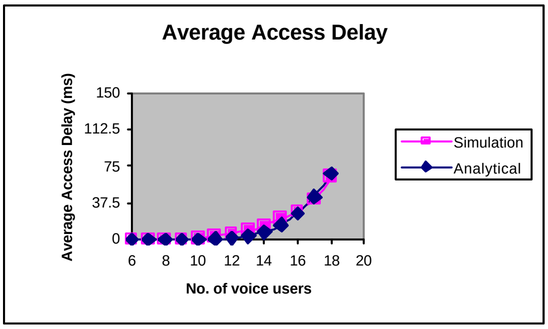

Figure 4: Average delay vs. number of voice nodes

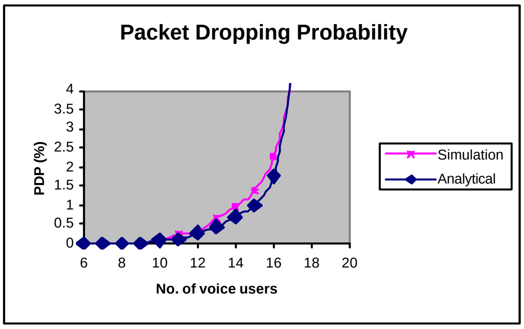

Figure 5: Packet Dropping Probability vs. Active Nodes

Nodes that wish to transmit when slots are unavailable are susceptible to dropping packets if the access delay exceeds a maximum value. As the number of active nodes in the cell increases, so does the probability of packets being dropped. Figure 5 shows the packet dropping probability (PDP) against the number of active nodes, which are all transmitting at single speech rate. The difference between the theoretical and simulation results in Figure 4 and 5 is attributed to the MAC transmitting. According to [5], to prevent speech quality from becoming indiscernible, PDP must be lower than 1 percent.

Since each node only requests one slot, the first nine nodes are easily accommodated, as there are nine available slots. The following nodes then have to wait for a slot to become available, which leads to PDP. At 1 percent, a maximum of ten nodes can be supported. Beyond ten nodes, the quality of service (QoS) is deemed unsatisfactory. The access delay correlates significantly with PDP.

7 CONCLUSIONS

This paper has proposed a design of a MAC protocol and a simulator for the protocol used for indoor optical wireless LANs using IR technology and with the wire line fibre optic network. A proposed scenario for such a LAN was presented and the MAC protocol was simulated. We evaluated the system performance for fixed number of voice sources in a cell over a range of system parameters. Computer simulations of the results agree with theoretical results. The performance of the protocol was determined by collating the PDP, system throughput and average access and transmission delays. The system has good stability and potential for further work.

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