CHAPTER 1

Introduction

1.1 Motivation

The exponential increase in deployment and use of "information appliances" such as digital still and video cameras, PDAs, music players, watches, mobile phones, laptops and handheld computers, leads to a demand for connectivity between them in a wireless manner. New devices have powerful "computer like" capabilities for storing, retrieving and processing of information such as portable information gathering appliances and palmtop computers. Laptop computers demand high-speed data wireless connections for accessing all services that are available on high-speed wired networks. Laptop users also wish to establish short-period wireless data connections for printing and for information exchange with a portable device.

Infrared and radio are considered as candidates for wireless connectivity. Infrared radiation offers several advantages over radio [8][57]. Infrared links utilize low cost components with small physical size and low power consumption. In addition, infrared spectrum is unregulated worldwide and can achieve high data rates. However, the infrared medium is not without drawbacks. Infrared emissions must obey eye safety limitations and are confined to the room of operation because infrared radiation cannot penetrate walls. Link quality can be detrimental due to ambient infrared noise and third user interference.

There are difficult challenges in designing wireless connectivity. Transmission range, transmitted power and modulation format issues must be addressed differently when a wireless medium is utilized. Carrier sensing and collision detection is more difficult in wireless than in wired connections. The desired station mobility and security issues must also be considered. In addition, there are different requirements for wireless connections. Depending on the application and on the devices involved, a wireless point to point or multipoint connection may be needed. For example, a digital camera requires a point to point connection with a laptop to transfer the pictures it holds in memory; a laptop requires LAN connectivity in order to share information with other laptops in range.

In order to avoid the development of non-interoperable single-vendor proprietary infrared link designs, the Infrared Data Association (IrDA) was established in 1993 by major IT companies aiming to develop standards for infrared connectivity. IrDA developed the IrDA 1.x protocol stack for short range, narrow beam, point to point connections. IrPHY, the IrDA 1.x physical layer, supports data rates up to 16Mbit/s. IrDA 1.x is widely adopted [16], fully supported by popular operating systems [106] and millions of devices are shipped every year embedding an infrared port for their wireless transfer needs [101].

IrDA addressed the requirement for multipoint connections with the development of the Advanced Infrared (AIr) protocol stack. The AIr proposal preserves the investment in IrDA 1.x upper layer applications by replacing the physical and the link layer of the IrDA 1.x protocol stack. A new physical layer, AIr PHY, is proposed that supports wide-angle infrared ports in order to achieve multipoint connectivity. AIr PHY base rate is 4 Mbit/s. AIr PHY employs Repetition Rate (RR) coding to achieve the increased transmission range required for wireless LAN connectivity. The transmitter trades speed for range by repeating the transmitted information RR times in order to increase the capture probability at the receiver. IrLAP, the IrDA 1.x link layer is divided into three sub-layers, the AIr Medium Access Control (AIr MAC), the AIr Link Manager (AIr LM) and the AIr Link Control (AIr LC) sub layers. AIr MAC is responsible for coordinating access to the shared infrared medium and for efficiently implementing RR coding. AIr LC provides guaranteed information delivery to the remote device.

The performance of wireless links may be measured by the link utilization, which can be drawn at the data link layer. Utilization is defined as the percentage of time the medium successfully transfers information between stations. Utilization takes into account all significant factors that affect performance such as (a) the physical layer delays (e.g. hardware latency), (b) the medium access mechanism, (c) the transmission control passing scheme, (d) the transmission errors introduced by the wireless medium and (e) the acknowledgement delays. Link layer design is very important as it must minimize physical and link layer delays and increase performance for the information transfer scenarios that will utilize the considered infrared link.

1.2 Statement of the problem

Link layer design must minimize physical and link layer delays such as hardware latency, medium access and retransmission delays. An efficient link layer must minimize utilization loss due to hardware latency delays and transmit large amounts of information before reversing link direction in order to decrease link turn around frequency. A single transmission error may result in the retransmission of a large amount of information data and utilization degradation. The determination of the optimum information amount that simultaneously minimizes retransmission overhead and hardware latency delays is addressed in this work. The implementation of an efficient transmission control passing mechanism for the specific link quality is also a link layer design challenge. In multipoint infrared connectivity, the development of an efficient medium access mechanism that minimizes collisions and channel idle time when many stations wish to utilize the shared medium at the same time is a challenge. The efficient implementation of coding schemes used to reach stations far away from the transmitter combined with retransmission schemes that cope with transmission errors is studied in this work.

1.3 Outline of research work

This work focuses on the efficient link layer design of infrared links based on IrDA proposals. The following issues are addressed:

a) **point to point infrared connections**

- The effect on utilization of wireless specific physical layer parameters is examined in order to determine the physical layer requirements for high performance. As the IrPHY supports half-duplex connections only, transmission control is passed at the IrLAP layer. The performance of different transmission control passing mechanisms is studied.
- Transmission errors are more likely to occur in wireless media. For example, the strict IrPHY range restriction (1m) can not be always met. A greater link distance may cause an increased error rate and utilization degradation. We derive optimum link layer parameter values that maximize utilization at high error rates. The utilization improvement of implementing optimum values for window size and the frame length is examined.

b) **Infrared wireless LANs**

- Access to shared infrared medium is coordinated by Carrier Sense Multiple

Access with Collision Avoidance (CSMA/CA) techniques. A station that is not able to hear transmissions originating from another station is called a hidden station. As hidden stations are likely to appear in infrared wireless LANs, the Request To Send / Clear To Send (RTS/CTS) medium reservation scheme is utilized to cope with the hidden station problem. AIr MAC always terminates medium reservation by an End Of Burst / End Of Burst Confirm (EOB/EOBC) frame exchange to inform all stations that current reservation is over and that the next contention period starts. The RTS and CTS control frames are transmitted using the maximum RR value (RR=16) in order to increase their transmission range. Thus, the employed CSMA/CA scheme may cause significant utilization degradation if it results in a significant number of collisions or empty collision avoidance slots. The performance of the proposed AIr MAC collision avoidance (CA) procedures is studied analytically. A mathematical model is developed assuming a finite number of stations and error free transmissions. The significance of the collision avoidance parameters and their effectiveness on utilization is examined.

- AIr LC employs a Go-Back-N (GBN) Automatic Repeat Request (ARQ) retransmission scheme to cope with transmission errors. However, AIr MAC optionally implements a Stop-and-Wait (SW) ARQ scheme as it may utilize frame level acknowledgments to efficiently implement RR coding. AIr MAC may also implement a GBN ARQ scheme acknowledging correctly received frames using the EOBC frame that terminates a reservation. We define five link layer protocols, which are referred to as a) frame level acknowledgement, b) frame level acknowledgement MAC, c) no frame level acknowledgement, d) no frame level acknowledgement utilizing LC ACK frames and e) sequential no frame level acknowledgment. These protocols provide a one or two layer ARQ scheme that copes with transmission errors. The effectiveness of the proposed ARQ protocols is compared under different channel conditions and for various application requirements.
- AIr MAC is responsible for implementing the suitable RR value for a specific link quality. The receiver monitors link quality and recommends RR values to the transmitter. The transmitter selects the RR it utilizes based (a) on the receiver

recommendations, (b) on the ARQ protocol it utilizes and (c) on the window size and frame length it implements. An analytical model that evaluates frame error rate as a function of SNR and RR is presented. The selection of ARQ protocol, RR value, window size and frame length that maximizes utilization is finally examined.

1.4 Thesis outline

The main scope of this thesis is to develop algorithms to support high speed and robust indoor infrared wireless connections. It focuses on the data link layer procedures that determine the performance of these links. Infrared point to point as well as LAN connectivity is considered. This thesis has four parts; chapter 2 discusses indoor connectivity, chapters 3 and 4 consider infrared point-to-point link layer issues, chapters 5, 6 and 7 study infrared multipoint connectivity and chapter 8 presents the conclusions.

Chapter 2 introduces wireless personal and local area networks, compares radio and infrared transmission media for indoor connectivity and discusses current standards for indoor links focusing on link layer issues. It presents the special characteristics of the infrared medium and discusses the link layer design challenges when the infrared medium is utilized at the physical layer. Chapter 2 also presents the two methods used in this work to address link layer design challenges; computer simulation and mathematical modeling. It finally presents the performance measures that evaluate performance and critically reviews current research in this area.

Chapter 3 presents the IrDA 1.x protocol stack and the IrLAP layer. It examines the IrLAP performance by developing a new analytical model for IrLAP utilization. The new model is compared with existing models in the literature and validated by comparing simulation with analysis results. The performance of IrDA 1.x links for various error rate conditions is presented and the effectiveness of physical and link layer parameters to link performance is studied. The IrLAP performance in the predicted future increases of IrPHY data rate is also examined.

Chapter 4 examines link utilization improvement for specific error rate conditions. It derives optimum window size values for fixed frame length and optimum frame length values for fixed window size by differentiating the utilization equation. Simple equations are derived that calculate optimum window and frame size values as a function of the link error rate and of physical layer parameters. The performance improvement when optimum values are implemented is discussed. If window and frame size can be simultaneously adjusted, new equations for optimum window and frame size are derived. Simultaneous window and frame size adjustment always achieves higher utilization. The practical IrLAP performance improvement that can be achieved if the transmitter utilizes optimum window and frame size values is examined using simulation techniques.

Chapter 5 presents the AIr protocol stack proposal for wireless LANs and focuses on the AIr MAC sublayer. It presents the interface between AIr MAC and PHY layers and analyses the AIr MAC collision avoidance procedures and transfer schemes, including the Reserved and Unreserved transfer modes of the protocol. It examines AIr performance using simulation techniques and analyses the performance of the Unreserved transfer mode for the particular PHY/MAC interface and collision avoidance scheme.

Chapter 6 develops an analytical model that calculates the performance of the collision avoidance (CA) procedures of the AIr protocol assuming no hidden stations and a finite number of contending stations. The model is validated by comparing analysis with simulation results and is employed to evaluate the effectiveness of the physical and link layer parameters to utilization assuming error free transmissions.

Chapter 7 considers link layer performance when transmission errors occur. It develops analytical models for five ARQ schemes that cope with transmission errors. It employs these models to examine the retransmission delays and the model developed in chapter 6 for the collision avoidance delays. It also presents an analytical model that calculates frame error rate as a function of signal to noise ratio when RR coding is implemented. By combining these analytical models, we calculate utilization as a function of the station's SNR, the implemented RR, the employed ARQ scheme, the turn around time delay and the utilized window and frame size values.

Chapter 8 presents the conclusions of this thesis and proposes direction for future research in the field of indoor infrared connectivity.