Performance Evaluation of IrDA Advanced Infrared AIr-MAC Protocol

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Abstract

Performance evaluation results of the Infrared Data Association (IrDA) Advanced Infrared Medium Access Control (AIr MAC) layer are presented. AIr MAC implements Unreserved and Reserved data transfer modes. Reserved mode employs the Request To Send / Clear To Send (RTS/CTS) media access reservation scheme. A simulator for the AIr MAC layer is developed. The importance of the Collision Avoidance Slot (CAS) window size limits and adjustments is investigated. The effectiveness of the proposed long CAS slot time and of the Physical layer Service Access Point (PSAP) primitives is explored in various network scenarios.

Keywords: Infrared Data Association, IrDA, AIr MAC link layer protocol, wireless communications, optical wireless links.

1. Introduction

Infrared Data Association (IrDA) was established in 1993 by major IT companies to develop and promote standards for infrared wireless connectivity. IrDA established Serial Infrared (SIR), a protocol standard for low-cost, low-power, short range, indoor, half duplex, point to point wireless links [1]. Almost every notebook computer and all Windows CE devices on market today are equipped with infrared ports following IrDA SIR.

To overcome several SIR limitations, such as point to point and range restrictions, IrDA recently developed a new standard for indoor LANs called Advanced Infrared (AIr). AIr Physical Layer (AIr-PHY) [2] supports data rates from 250Kbps to 4Mbps using four-slot Pulse Position Modulation with Variable Repetition Encoding (4PPM/VR) with a base data rate of 4Mbps. Variable Repetition Encoding introduces redundancy used to improve Signal To Noise (SNR) ratio. Better SNR provides additional transmission range.

IrLAP [3], the IrDA SIR link layer, was split into three sub-layers, the AIR Medium Access Control (AIR-MAC) [4], the AIR Link Manager (AIr-LM) [5] and the AIr Link Control (AIr-LC) sub-layers. AIr specifications are still in draft state and address certain MAC issues differently than similar MAC protocols. In particular, AIr MAC implements a much longer Collision Avoidance Slot (CAS) time than IEEE 802.11, new CAS window size adjustment, different physical layer primitives and Reserved and Unreserved data transfer modes.

AIr performance for different load conditions using an OPNET™ simulator was explored in [6] and AIr's Reserved mode performance in saturation conditions was explored in [7]. The AIr simulator using C/C++ developed in [7] was modified in current work to exploit the effectiveness of the Unreserved data transfer mode. Simulation results here are focused to MAC issues addressed differently in the AIr specification than in similar protocols.

2. The AIr-MAC Protocol

The AIr frame format is presented in Fig. 1. The AIr MAC sublayer allocates the infrared medium to competing stations by employing CSMA/CA techniques. A competing station first selects a random number of CAS slots to wait in the range from zero to CAS Window size. AIr MAC specification defines that the CAS window size must be >=7 and <=255. If during this wait period another transmission is observed, the station freezes the CAS timer. The timer is restarted again when the on-going transmission has finished and the next contention period is started. When the CAS timer reaches zero, the station transmits.

The AIr MAC provides, among others, reliable and unreliable data transfer, adaptive data transfer rates and reservation media access by employing Request To Send / Clear To Send (RTS/CTS) packet exchange as shown in Fig. 2(a), 2(c) and

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Preamble	Sync	Robust Header	Main Body	CRC
256bits RR=1	160bits RR=1	32bits RR=16	variable length variable RR	32bits variable RR

Figure 1. AIr frame format

2(d). The transmitting station reserves the medium for the duration contained in the Reservation Time (RT) field of the RTS frame it transmits. The receiving station echoes the reservation period in the RT field of the responding CTS frame. Thus, even stations being able to hear only the RTS or only the CTS frame refrain from transmitting for the entire reservation period. The RTS/CTS scheme is used to address the hidden station (a station not being able to hear the transmitter or the receiver) problem [8] at the expense of the time required for transmitting the RTS and CTS frames. After the last data frame is transmitted and before the reservation time expires, the transmitter can request termination of current reservation by transmitting an End Of Burst (EOB) frame (Fig. 2(a) (c) (d)). The receiver responds with an End Of Burst Confirm (EOBC) frame confirming termination of current reservation. As with RTS/CTS exchange, a station hearing only the EOB or the EOBC frame knows that the current reservation is over and is able to contend for the medium again.

AIr transfer modes are shown in Fig. 2. Unreserved data transfer mode (Fig. 2(b)) transmits only one UDATA data frame to a Multicast or Broadcast (i.e. all devices) address using Repetition Rate (RR) =16 to ensure maximum coverage. This is the simplest and most unreliable method as no acknowledgement is received. The Unreserved mode does not reserve the infrared medium by transmitting RTS and CTS frames, thus incurring the least overhead. Reserved transfer mode with no acknowledgements (Fig.2(a)) uses the RTS/CTS reservation scheme but it is still unreliable as no acknowledgements are exchanged. When one of the above two data transfer modes is used, a MAC successful transmission indication to LM layer means that the frames are sent and not that the frames are correctly received. Reserved transfer mode with acknowledgement (Fig 2(c)) and Reserved transfer mode with Sequenced data (Fig.2(d)) use the RTS/CTS reservation scheme and successful data reception is based on an immediate acknowledgement packet (ACK) and on a receiver’s

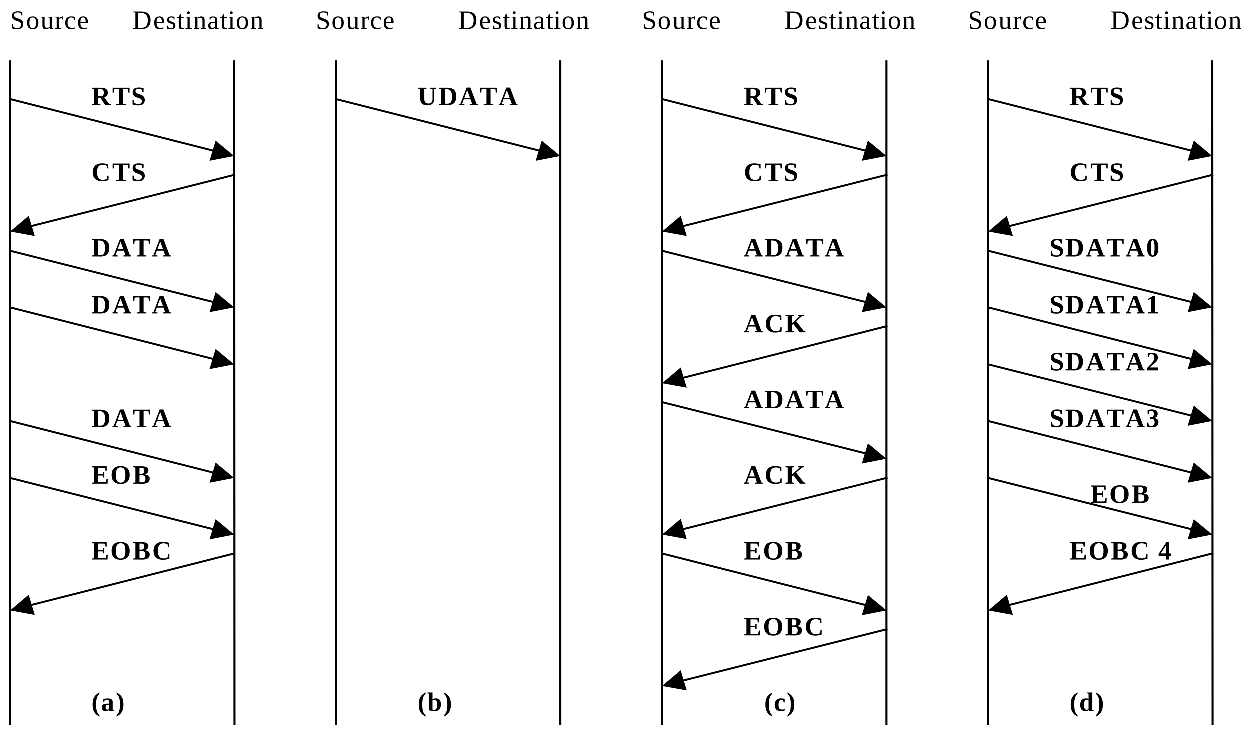

Figure 2. *(a) Reserved mode transfer with DATA frame (no acknowledgement) (b) Unreserved mode transfer with UDATA frame (c) Reserved mode transfer with Acknowledgement (d) Reserved mode transfer with Sequenced Data.*

PSAP Primitive	abbreviation	type	explanation
AIr PHY Carrier Sense Detect	CSD	indication	Preamble (PA) portion of an incoming frame detected
AIr PHY Carrier Sense Confirm	CSC	indication	SYNC portion of an incoming frame detected
AIr PHY Robust Header Received	RHR	indication	Robust Header portion of an incoming frame received
AIr PHY Main Body Received	MBR	indication	Main Body portion of an incoming frame received
AIr PHY Frame Transmit	FTX	request	MAC request a frame transmission
AIr PHY Frame Transmission Completed	FTC	indication	MAC frame transmission completed

Table 2. AIr Physical layer Service Access Point Primitives

indication in the EOBC packet of the next frame expected respectively. For these two modes, a MAC successful transmission indication to LM layer means that the frames are correctly received.

The AIr MAC employs the variable Repetition Rates presented in Table 1. A higher RR is used to reach a station that is far away from the transmitter by repeating the information transmitted, thus trading speed for range. The Robust Header (RH) is always transmitted in RR=16 to ensure that all stations receive the vital information contained in RH. This information includes the Reservation Identifier (RID) field, the type of frame transmitted, the RT period, the RR of frame's main body, etc. Main Body (MB) is transmitted at the RR suitable for the link quality from the transmitting to receiving station.

Repetition Rate	Data rate
RR=1	4 Mbps
RR=2	2 Mbps
RR=4	1 Mbps
RR=8	500 Kbps
RR=16	250 Kbps

Table 1. AIr RR enumeration

The AIr MAC uses the service primitives provided by the physical layer through the AIr Physical layer Service Access Point (PSAP). AIr PHY passes information about frame reception to AIr MAC by PSAP service primitives called indications. AIr MAC calls for frame transmissions by invoking PSAP primitives called requests. Indications and requests for single frame transmission used in current model are presented in Table 2. and explained in Fig 3.

3. Simulation model

In the current work, the effectiveness of the Unreserved data transfer mode (Fig2(b)) is evaluated. Unreserved mode is employed only for Multicast or Broadcast transmissions, so only a small number of stations may employ Unreserved mode in real life scenarios. A network of *n* stations operating on saturation conditions is considered, meaning that every station always has a frame ready for transmission. The majority of the stations always employ the Reserved transfer mode with no acknowledgements, transmitting only one DATA frame in each reservation. This reservation scheme was chosen as it employs the least overhead among

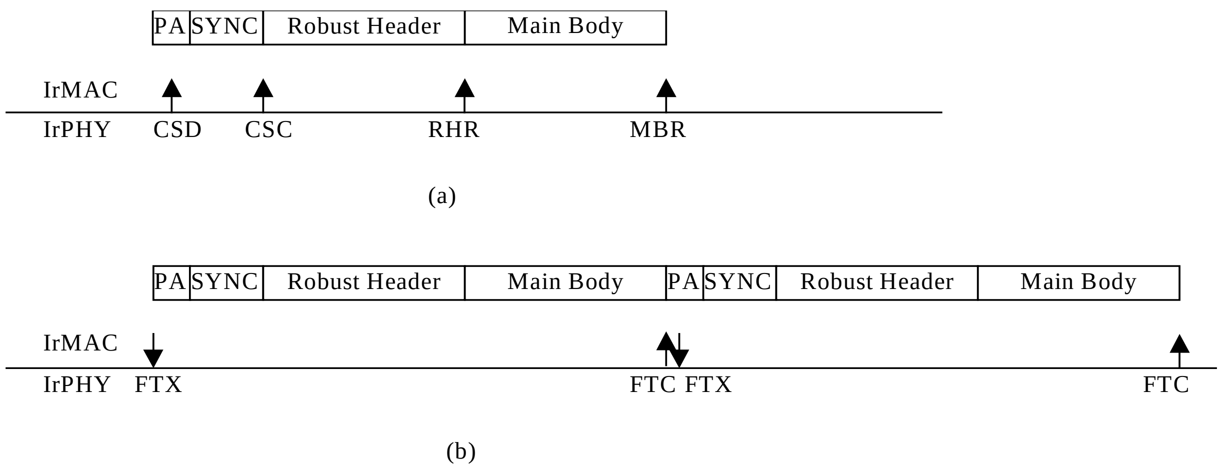

Figure 3. Physical layer Service Access Point primitives *(a) frame reception (b) frame transmission*

	Restriction	Suggested	Implemented
		usec	usec
T_{RTS}(RR=16)		244	244
T_{PA}		64	64
T_{SYNC}		40	40
T_{RH}		232	232
Turn Around Timer (TAT)		200	200
CAS	$>T_{RTS}+TAT+T_{PA}+T_{SYNC}$	800	800
WFCTS Timer	$>=TAT+T_{RH}$	632	556
EXIT2 Timer	=TAT	200	200

Table 3. AIr timers and packet element transmission times.

AIr MAC's reservation schemes. DATA frames always carry 16Kbits of user data (the maximum allowed by AIr MAC protocol) and use a RR=1 for 4Mbps data rate.

A small number (one or two) of the *n* stations is assumed to have multicast or broadcast data and thus employ the Unreserved data transfer in saturation conditions, i.e. these stations always have a UDATA frame ready for transmission. To accomplish direct comparison with DATA frames, every UDATA frame always carries 16Kbits of user data and is transmitted with RR=1. AIr MAC's suggestion to use the maximum Repetition Rate (RR=16) in every multicast or broadcast transmission is not effective as the data rate is dropped to 250Kbps even in scenarios that all stations are close enough to the transmitting station to hear at the maximum data rate of 4Mbps. Should a RR=16 is used for UDATA frames, UDATA frame transmission requires sixteen times the transmission time needed for a DATA (RR=1) transmission, making comparison of UDATA and DATA throughput difficult. Should a RR=16 be used for UDATA transmissions and to avoid channel domination of UDATA transmissions, the results of this work can be interpreted as involving UDATA frames with 1Kbits of user data transmitted at RR=16.

The current model assumes that there are no transmission errors and no hidden stations. In other words, all packets are transmitted error free to all stations except from packets that experience collisions. Protocol timer values and times required for transmitting frame elements are presented in Table 3. Protocol suggested values and restrictions are also presented for comparison. All protocol suggested values by AIr standard are implemented with the exception of the Wait For CTS proposed timer value. In this case, a different value that obeys protocol restrictions and enables station synchronisation is selected.

4. Simulation results

Fig. 4 shows total (DATA and UDATA) and Unreserved (UDATA) throughput performance versus fixed CAS window size for one station employing UDATA transmissions and for various network sizes. If a small CAS window size is implemented, throughput seriously degrades with the increase of the network size as the number of collisions is increased. If a large CAS window size is implemented, throughput degrades, especially for small networks due to the increase of empty CAS time slots. Proper CAS window selection is very important for accomplishing maximum throughput for a specific network size. Fig. 4 also shows that optimum CAS window size increases as the network size is increased.

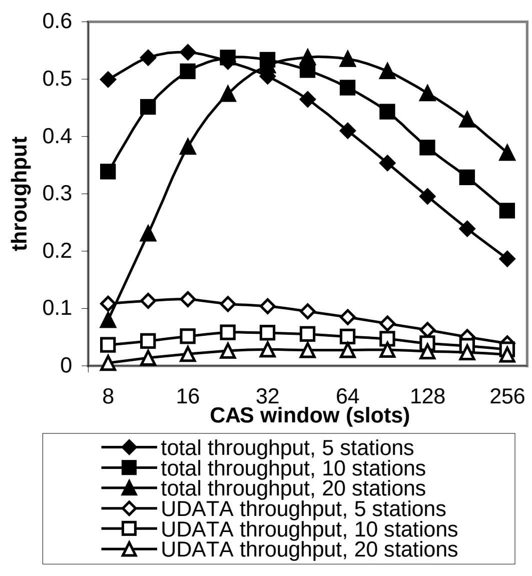

Figure 4. Throughput efficiency versus CAS window size. *C=4Mbps, l=16Kbits, ppb=1, 1 UDATA station.*

Fig. 5 plots the total and UDATA throughput versus network size for different fixed CAS window sizes. It shows drastic throughput decrease with the increase of network size due to the increase of the number of collisions. As collisions may involve a large UDATA frame, collision duration is very long and affects small CAS window sizes more drastically as the collision probability increases with the decrease of CAS window size. The degradation of UDATA throughput for large network sizes can be easily explained as the number of stations providing reserved data is increased with the network size increase and only one station is still employing UDATA transmission.

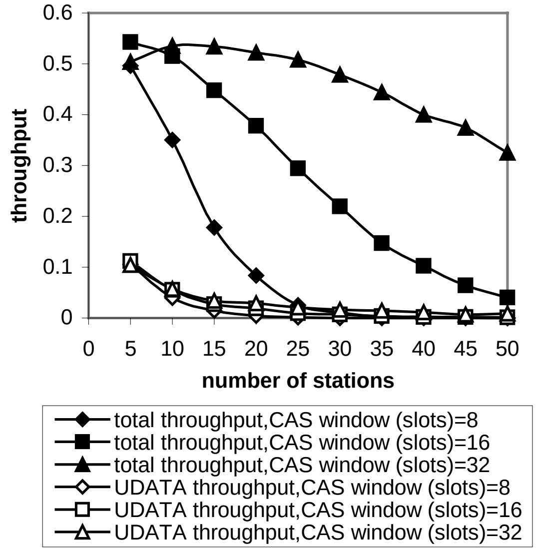

Figure 5. Throughput efficiency versus number of stations*. C=4Mbps, l=16Kbits, ppb=1, 1 UDATA station.*

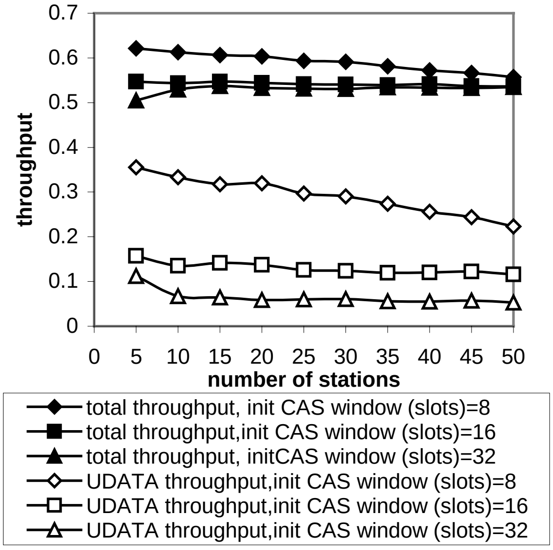

Figure 6. Throughput efficiency versus number of stations*. Reserved stations with CAS window adjustment. C=4Mbps, l=16Kbits, ppb=1, 1 UDATA station.*

The important issue of the proper selection of the implemented CAS window size is addressed in the AIr standard by enforcing rules for incrementing and decrementing CAS window size after unsuccessful and successful transmissions respectively. A CAS window size increase of 4 after every unsuccessful transmission and a CAS window size decrease of 4 after every successful transmission is implemented for every station employing the reserved method. However, CAS window size adjustment is not possible for a station employing the Unreserved data transfer as this station is unaware of the reception status of its UDATA frame and it is also unaware of whether a collision occurred or not. Total and UDATA throughput results are shown in Fig. 6 with one station employing the Unreserved transfer mode and the remaining stations employing the Reserved transfer mode with a ±4 CAS window size adjustment. Total throughput slightly decreases with the increase of the initial CAS window size and it is practically independent of the network size. UDATA throughput is very high especially for large network sizes when a large number of stations employ the reserved access scheme. The situation is explained as follows. When a UDATA frame is involved in a collision, the collision duration is extended to the time required for the complete UDATA frame transmission. The remaining stations are unaware of the collision existence since the AIr PHY layer, (as shown in Table 2 and Fig. 3), does not send an indication to its upper MAC layer unless a valid preamble portion of an incoming frame is detected. The remaining stations continue contending for the medium resulting unsuccessful reservation attempts in the collision duration. As the CAS window size is increased after every unsuccessful reservation attempt, the stations employing Reserved data transfer use large CAS window sizes, thus reducing the probability of gaining access to the infrared medium. At the same time, the station employing Unreserved data transfer employs the smallest available CAS window size, thus increasing the probability of a UDATA frame transmission.

Fig. 7 plots total and UDATA throughput versus fixed CAS window size for different network sizes when two of the contending stations employ the Unreserved data transfer mode. Direct comparison with Fig. 4 reveals that throughput degradation, especially for small CAS, is observed when a second station employs the Unreserved instead of the Reserved data transfer mode. The reason is that, again, when a UDATA frame in involved in a collision, the collision duration is very long. As the other station employing UDATA frame transmissions is unaware of the collision existence, it will continue contending for the medium and probably transmit its UDATA frame during the collision. This fact clearly extends the collision duration resulting in throughput degradation. Fig. 8 plots total and UDATA throughput versus network size for different initial CAS window sizes when two stations employ the Unreserved data transfer mode and the remaining stations employ the Reserved mode with the proposed ±4 CAS window size adjustment. Comparison with Fig. 6 reveals that throughput now decreases, especially for small CAS values, with a network size increase as the probability of long collisions is increased. It also shows that UDATA throughput portion per station is increased and UDATA transmissions dominate over DATA transmissions as the Reserved stations increase their CAS window size more frequently as the UDATA collisions last longer.

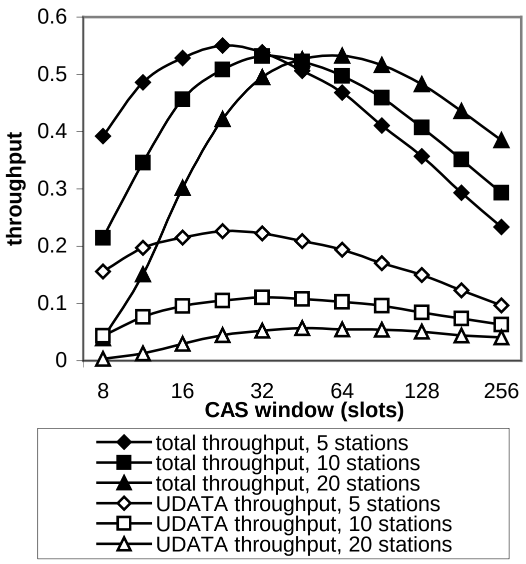

Figure 7. Throughput efficiency versus CAS window size. *C=4Mbps, l=16Kbits, ppb=1, 2 UDATA stations.*

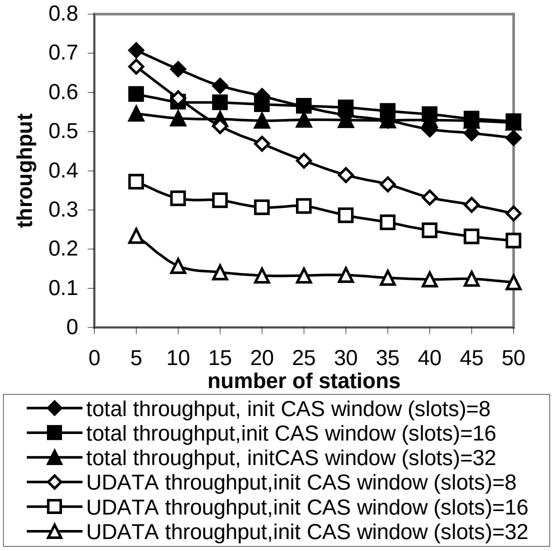

Figure 8. Throughput efficiency versus number of stations. *Reserved stations with CAS window adjustment. C=4Mbps, l=16Kbits, ppb=1, 2 UDATA stations.*

5. Conclusions

A simulation model for the proposed AIr MAC protocol employing both the proposed Unreserved and Reserved data transfer modes is developed. Throughput performance for different network and CAS window sizes varying the number of stations employing the Unreserved data transfer mode is presented. Employment of the Unreserved data transfer mode along with the proposed Physical layer Service Access Point (PSAP) primitives, that does not contain an indication for medium busy condition, results in unexpected behaviour. When a station employing Unreserved access scheme is involved in a collision, the collision duration extension results unexpected CAS window size adjustments to stations employing the Reserved access scheme. The resulting UDATA frame medium domination and throughput degradation renders the Unreserved access scheme unsuitable for AIr networks, even in scenarios that only a few stations employ the Unreserved data transfer mode.

6. References

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