A study of link processing time and propagation delay for IrDA links at Gbit/s data rate

P. Huang, P. Chatzimisios and A.C. Boucouvalas
Multimedia Communications Research Group
School of Design, Engineering and Computing
Bournemouth University, Fern Barrow, Poole, BH12 5BB, U.K.
Email: {phuang, pchatzimisios, tboucouv}@bournemouth.ac.uk

Abstract

Indoor infrared links are anticipated to reach Gbit/s or even higher data rates in the future. The aim of this paper is to examine how the existing IrDA IrLAP protocol performs at very high data rates. We develop a mathematical model for IrLAP, the link layer protocol of IrDA taking into account the effect of packet processing and propagation delay on link thoughput. We derive the optimum window size that maximises throughput performance and we validate the accuracy of our mathematical analysis by comparison with exact numerical methods. The results presented in the paper explore the effects of both packet processing time and propagation delay on the performance of high-speed IrDA links.

1. Introduction

The past few years, portable devices have seen a rapid growth and there is an increasing demand for wireless data connectivity. Recent advances in wireless technology have equipped portable devices with wireless capabilities that allow networked communication even while a user is mobile [1]. The ideal goal of wireless communication is that users can access real-time information anywhere without the need to be wired.

The IrDA protocol specification was developed by inclusive organisations to provide short-range, low-cost, indoor, point-to-point links utilizing the IR spectrum. IrDA also offers the advantage of being easy to implement and simple to use, in addition to the high data rates [2]. IrDA links aim to replace cables between devices such as laptop computers, personal digital assistants (PDAs), digital still and video cameras, mobile phones and printers. The ‘point and shoot’ nature of the IrDA user model requires line of sight link alignment, and as a result short data transfer times are important. As the trend of using larger files combined with the need for faster file transfer times continues to become more important, there will be a great need for much faster short range wireless links [3].

The IrDA standard defines links offering half-duplex, short range links of data rates ranging from 115.2 Kbit/s [4] to 16 Mbit/s with high-speed extensions [5]. As existing IrDA links are currently being examined for future evolution to 100Mbit/s and beyond to Gbit/s data rate, backwards compatibility with previous generation products is of much interest [1]. The existing IrDA IrLAP link layer protocol [6] is running on top of the physical layer of the devices. The important factors affecting the performance of IrLAP are the minimum turnaround time, packet processing time, propagation delay and packet error rate.

In this paper, we develop a mathematical model for IrLAP using the concept of “window transmission time” (WTT). This model takes into account the packet processing and propagation delays, which become important especially at high data rate IrDA links. We validate our mathematical analysis and we explore the effect of both packet processing and propagation delay on the performance.

Our paper is organized as follows: Section 2 introduces IrLAP and defines several parameters, which are used in the mathematical modelling. In section 3 we carry out a comprehensive analysis and derive the link layer throughput equation. Furthermore, window size is optimised in order to maximise throughput performance. Section 4 provides several numerical results, which show significant improvement on performance by adopting the optimised window size. Finally, section 5 concludes the paper.

2. IrLAP Description and Parameter Definitions

IrDA IrLAP, a derivative of the HDLC protocol [7], is presented in detail in [8]. In this paper, the concept of the “Window Transmission Time” (WTT) is used to denote the average time needed for a complete window transmission [7]. WTT represents the time needed from the beginning of the window’s first frame transmission to the beginning of the next window’s first frame transmission. WTT incorporates time needed for a complete window frame transmission of I-frame (information frame) transmissions, acknowledgements for the received frames, delays for reversing the direction of the link and time consumed in possible timer time-out delays.

For ARQ protocols, as described in [9], [10] and [11], WTT also includes the time needed for preparing each frame for transmission (p_1), processing the received frames by the receiver (p_2) and time for processing the acknowledgement in the transmitter (p_3). According to [9], $p_1 = p_3 = 4 \cdot 10^3/v$, where v is the processor speed of the wireless device in MHz. The processing times p_1 and p_2 are mainly consumed on calculating the 32-bit CRC upon preparation and reception of a frame respectively for the purpose of checking the frame for errors. For this reason, it can be assumed that $p_1 = p_2$. Therefore, the frame processing times are equal to: $p_1 = p_2 = p_3 = 4 \cdot 10^3/v$.

In Fig.1, an IrLAP transmission process is illustrated. Fig.1(a) shows a window transmission of 7 frames, with no errors. Fig.1(b) shows the case of a frame in error (frame #2). Finally,

Fig.1(c) illustrates an error in frame #2 but also an error in frame #6 where the Poll bit (P-bit) was set and lost. The transmitter is setting the P-bit to reverse link direction and to request a response from the receiver. If the last frame that contains the P-bit is not correctly received, the receiver doesn't respond. The transmitter waits for a period t_{Fout} and sends a S-frame (supervisory frame) forcing the receiver to acknowledge the received frames. The receiver sends a response indicating the next expected data frame if all frames are received without errors. If at least one frame is received in error, then the receiver responds pointing out the first erroneous frame.

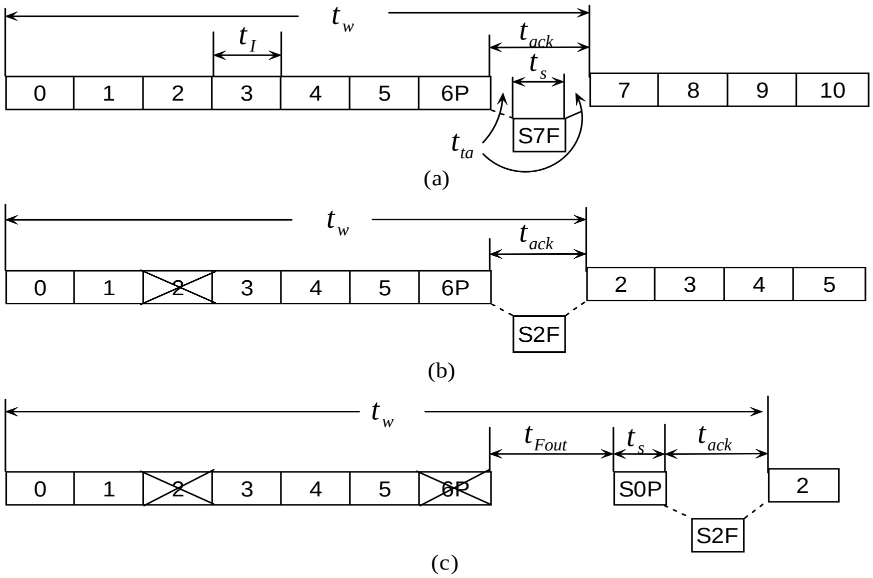

Figure 1 A seven frame IrLAP transmission model

In our work the saturation case is considered. The transmitter always has information ready for transmission and a window of *N* frames will be transmitted before the link reverses direction. Moreover, we consider a hardware architecture, which is represented by the timing diagram of fig. 2, in order to explore the effect of propagation delay and processing time on IrLAP throughput. Again, an example window transmission of 7 frames is considered.

The transmitter prepares the first frame *f1* consuming time p_1. The frame is transmitted and arrives at the receiver with a delay equal to t_p due to the propagation delay. The receiver needs time equal to p_2 to process the frame and the transmitter prepares the next frame (f_2). After sending the last frame (f_7), the transmitter waits for an acknowledgement packet. The receiver processes the last frame (f_7) and the station's receiver circuit require time t_{ta} to recover after the transmission and to revert to transmitting mode. Following this turnaround time, the receiver sends an acknowledgement packet and it takes p_3 time for the transmitter to process it. Subsequently, the sender can continue with a new window transmission of frames. Referring to the IrDA standard [6], the maximum value of the window size *N* is 127 and the frame size varies between 128 bits and 16384 bits.

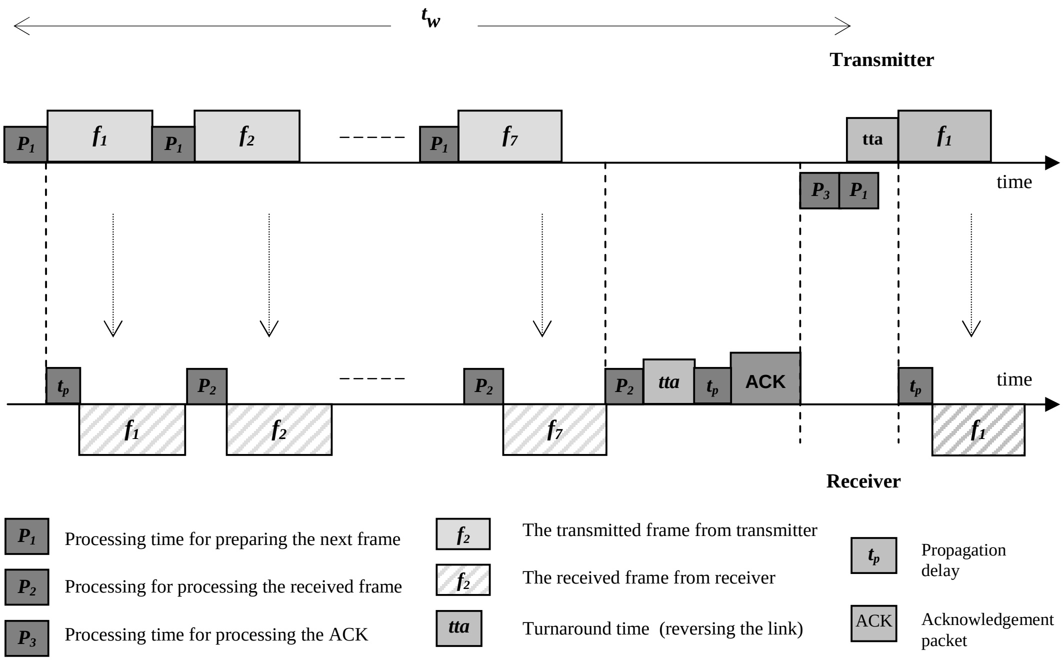

Figure 2 Timing diagram of a data frame transmission for window size of 7

3. Mathematical model and optimum window size analysis

The parameters used in the current analysis are shown in Table 1.

Symbol	Parameter Description	Unit
c	Speed of light	m/sec
C	Link data rate	bits/sec
d	Distance between transmitter and receiver	m
p	Frame error rate	-
p_b	Link bit error rate	-
N	Number of frames in one window	-
l	I-frame message data length	bits
l'	S-frame length/ I-frame overhead	bits
v	Processor Speed	MHz
p_1	Preparation time of an I-frame	sec
p_2	Processing time of an received I-frame	sec
p_3	Processing time of an S-frame	sec
t_s	Transmission time of a Supervision (s)-frame	sec
t_{ta}	Minimum turn-around time	sec
t_{ack}	Acknowledgement time	sec
t_{Fout}	F-timer time-out period	sec
t_p	Propagation time	sec
D_b	Data throughput	bit/sec

Table 1 Parameters used in modelling IrLAP throughput

Moreover, the values for t_S, t_I and p are given by:

$$t_S = \frac{l'}{C}, \quad t_I = \frac{l+l'}{C}, \quad p = 1-(1-p_b)^{l+l'}, \quad t_{Fout} = t_I + 2t_{ta}, \; t_p = \frac{d}{c} \tag{1}$$

In [8] the throughput of an IrDA wireless link was derived without considering the influence of propagation delay and processing time:

$$D_b = l\frac{1-p}{p}\frac{\left(1-(1-p)^N\right)}{t_w} \tag{2}$$

In this paper, we consider frame processing time and propagation delay, the window transmission time (WTT) becomes equal to:

$$t_w = Nt_I + p(t_{Fout} + t_s + 2t_p) + t_{ack} + (N-1)p_1 + 2t_p \tag{3}$$

where t_{ack} is the acknowledgement time of a frame and includes processing times:

$$t_{ack} = 2t_{ta} + t_S + p_2 + p_3 \tag{4}$$

Consequentially, we derive the following equation for the data throughput D_b taking into account the effect of processor speed and propagation delay as given by:

$$\boxed{D_b = l\frac{1-p}{p}\frac{(1-(1-p)^N)}{Nt_I + p(t_{Fout} + t_s + 2t_p) + t_{ack} + (N-1)p_1 + 2t_p}} \tag{5}$$

In fact, equation (5) is a function of both window size N and frame size l. In order to achieve maximum throughput performance, optimum window size N values for fixed frame size l will be derived next. We differentiate equation (5) by taking $\frac{\partial D_b}{\partial N} = 0$. For small p, we can assume that:

$$(1-p)^N \approx 1 - Np + \frac{N(N-1)}{2}p^2$$

We can also approximate that $t_{ack} + 2t_p - p_1 + p(t_{Fout} + t_s + 2t_p) \approx t_{ack} + 2t_p - p_1$, $p << 2$, $t_I \approx \frac{l}{C}$, and $p \approx lp_b$.

After some algebra, the optimum window size N_{opt} is given by:

$$N_{opt} = \sqrt{\frac{2(t_{ack} + 2t_p - p_1)C}{lp_b(l + p_1C)}} - \frac{(t_{ack} + 2t_p - p_1)C}{l + p_1C} \tag{6}$$

4. Analysis results

In order to examine the effect of propagation delay and processing time on the high-speed links, a comparison between the link throughput efficiency with and without considering the propagation delay and processing time is studied next by using equations (5) and (2) respectively. In Fig.3, the IrLAP throughput efficiency is plotted against link data rate in different BER values of 10^{-8}, 10^{-7} and 10^{-6}. The other parameters are given values as follows: frame size l =10Kbit , window size N=127 , minimum turnaround time t_{ta}=10^{-6}s *, link distance d=3m and processor speed v=300MHz. Unless otherwise specified, the previous parameter values are used throughout this paper.

In Fig.3, the throughput efficiency (TPE), including the propagation and processing delay, decreases when the data rate increases for all BER cases, while without considering the delays, the TPE is having nearly of constant throughout the data rate range. Significant differences between the TPEs with and without considering the delays are observed in the figure. The differences indicate the considerable effect of propagation delay and processing time. The effect is more pronounced at high data rate for all BER cases. For instance, there is nearly 60% TPE difference at 1Gbps for both BER of 10^{-8} and 10^{-7}. Due to the significant detriment of propagation delay and processing time at high data rates, optimising the IrLAP parameter for maximum link throughput is, therefore, very important.

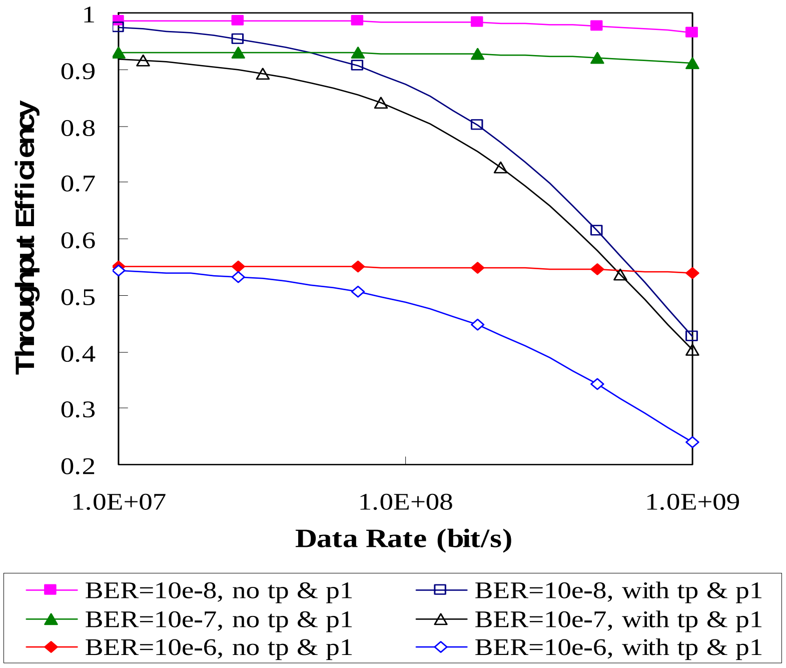

Figure 3 Throughput comparison exploring the effect of propagation delay and processing time

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* since we are not examining here in detail the effect of t_{ta} , we have chosen it as a parameter with a very small value so as it has negligible effect and this way to allow us to examine the processing speed and propagation time in isolation

Fig.4 plots optimum window size versus BER for three data rates (C = 10Mbit/s, 100Mbit/s and 1Gbit/s). Comparing the optimum window size results obtained from equation (6) with results obtained from exact numerical methods, shows very good agreement. Therefore, Fig.4 validates all the approximations used to derive equation (6). Moreover, the figure illustrates that optimum window size depends significantly on BER values. In fact, N_{opt} is decreased when BER increases in order to cope with the increased number of frame errors.

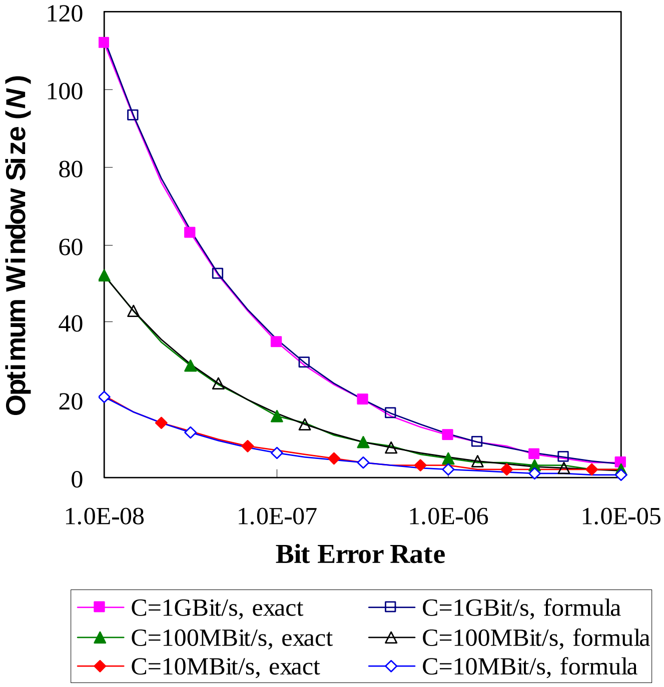

Figure 4 Optimum window size validation for v=300 MHz

Fig.5 plots optimum N values and the corresponding throughput efficiency versus data rate for various BER values (BER = 10^{-8}, 10^{-7} and 10^{-6}). It is observed that data rate affects both throughput efficiency and optimum window size. When data rate increases, throughput efficiency is reduced for any BER value. Moreover, when there is an increase of data rate, optimum window size increases particularly when the number of frame errors is low ($BER = 10^{-8}$). Furthermore, a comparison between Fig.3 and 5 shows that optimisation of window size is necessary since the performance is significantly improved when optimum window size values are used. Especially, in the case of $BER = 10^{-6}$, optimisation proves to be vital for the performance of the wireless link.

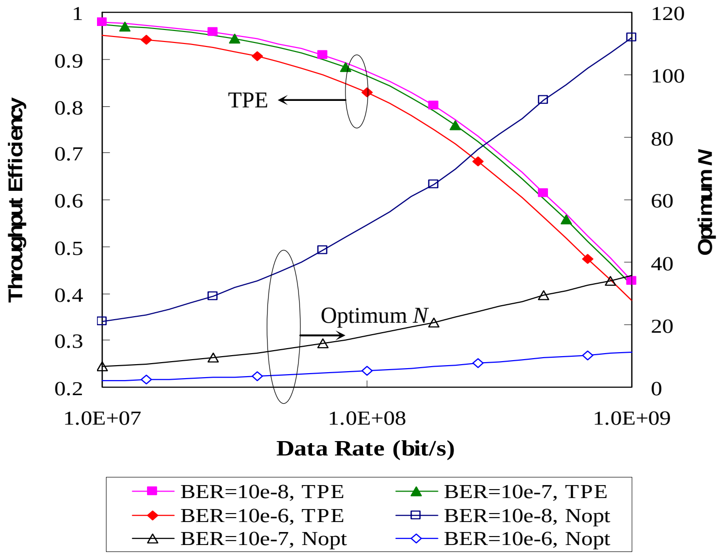

Figure 5 Throughput efficiency using optimum window size and the corresponding optimum window size for v=300 MHz

Finally, Fig.6 explores the dependence of throughput performance on processor speed for data rate of C=1Gbit/s. By setting $tta = 10^{-6}$, we ensure that the effect of turnaround time on throughput is negligible. In order to examine only the effect of processing time, we also set the link distance equal to zero. With the above assumptions we can isolate the effect of processor speed. In Fig.6, we consider five possible processor speeds (v=300MHz, 600MHz, 1GHz, 2GHz and 50GHz) for a wireless device. In all cases, figure illustrates that processor speed highly affects the performance of a wireless link. Employing high processor speeds, this boundary does not exist anymore and performance is improved significantly. Moreover, we can observe that performance also depends on BER and degrades when BER increases.

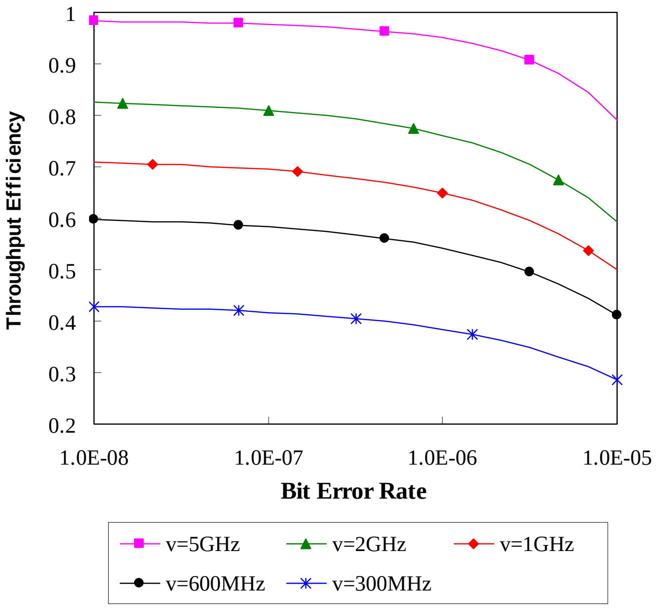

Figure 6 Throughput efficiency for different processing speed using N_{opt}

Next we consider the impact of propagation delay alone on IrLAP throughput. This is shown in Fig.7, which plots throughput efficiency against BER for different data rates, v=50GHz and t_{ta}=0 (in order to eliminate the effect of both the processing time and propagation delay) and for two distances (d=0 and 3m). The figure depicts that when data rate is C= 1Gbit/s, propagation time between the wireless devices does not influence the performance of the link. When data rate is higher (C= 10Gbit/s), propagation delay begins to affect throughput performance. For this reason, the difference between the throughput efficiency values, with and without considering the propagation delay and processing time (Fig.3), are mainly due to the processor speed of a wireless device. Moreover, we can observe that propagation delay and as a result, distance play an important role for data rates of the wireless link approaching 10Gbit/s.

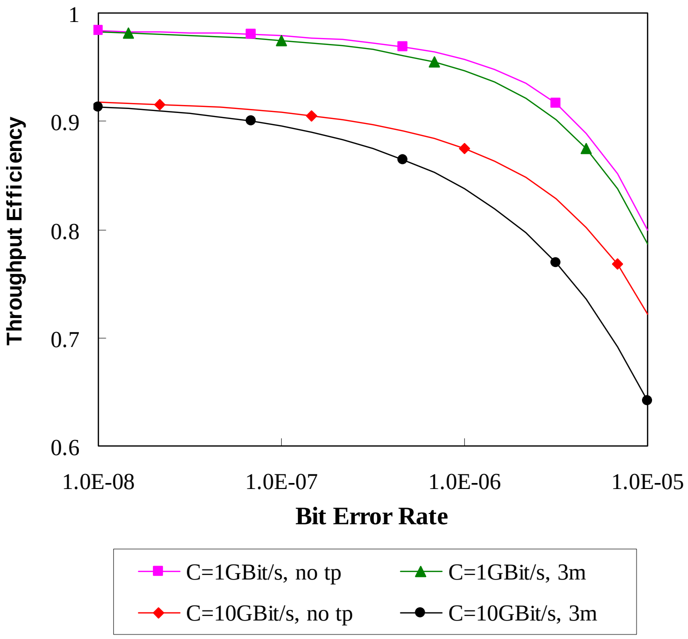

Figure 7 Throughput efficiency for various data rates and distance using N_{opt} for v=50GHz

5. Conclusions

This article examines the performance of IrDA IrLAP protocol operating at Gbit/s data rates. A systematic analysis of IrLAP protocol has been carried out by including the effect of the processing speed and propagation delay. In order to maximise the link throughput, we derived and validated the BER dependent equation for optimum window size. Numerical results show that throughput is significantly improved by employing the optimized window size. Results also show that processing speed has a considerable effect on the link throughput. We offer guidelines on the appropriate processing speed so that the system performance is always maximised for future high-speed links. Finally, we show that the effect of propagation delay on throughput depends on data rate and the impact becomes important for data rates approaching10Gbit/s.

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