The Performance of Robust Adaptive Modulation over Wireless Channels with Non Reciprocal Interference

R. Cepeda, M. Fitton and A. Nix[1]
Toshiba Research Europe Limited
32 Queen Square, Bristol BS1 4ND, UK
Email: rafael.cepeda@toshiba-trel.com

Abstract*-Adapting a modem's modulation scheme can significantly enhance the resulting performance over a wireless communications link. Non-adaptive modems are generally designed conservatively for worst-case channel conditions. Adaptive modems are able to exploit the higher channel capacity when good conditions are encountered. A number of different metrics can be used to drive the adaptation process (i.e. Automatic Repeat reQuest (ARQ) or Segment Error Rate (SER)). Not surprisingly, certain metrics are far more successful than others. This paper presents an investigation of adaptive modulation in the presence of interference. In particular, the case of non-reciprocal interference is studied (i.e., cases where the level of interference is different on the forward and reverse links). Research results have shown that if adaptation is performed assuming a reciprocal channel, then poor performance will result for the link experiencing a higher level of interference. In this study, an algorithm is used to calculate a measure of the link quality. This value is then fed back to the other end of the link to adapt subsequent transmissions. Results indicate that the throughput of such a system can be considerably improved when transmitting adaptively using any one of DBPSK, DQPSK or 8DPSK modulation schemes. It is proposed that this simple approach be adopted for short range, ad hoc, Wireless Personal Area Networks (WPAN).

I. INTRODUCTION

In recent years link adaptation has been a major area of research. It has been shown that the use of any fixed modulation scheme is not efficient in terms of utilisation of bandwidth. For adapting, different metrics can be used to determine when best to switch either the modulation scheme, power level or coding rate. Automatic Repeat Request (ARQ) or Segment Error Rate (SER) are two leading metrics that can be employed for adaptive modulation. The term "*Segment Error Rate*" is used here as it assumed that each packet is divided into a number of segments as shown in Fig. 1.

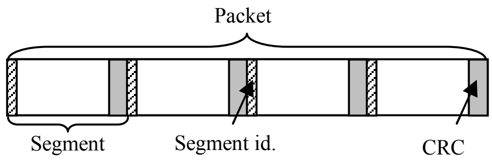


Fig. 1. Packet structure.

The information necessary for adapting can be implicit or explicit. Let us assume that two nodes (A and B) communicate over a time division duplex channel and that node B must now choose a modulation scheme for transmission back to node A. An implicit scheme would adapt based on information available from the last received packet at node B. An explicit scheme would adapt based on data sent back from node A to enable the conditions at the other end of the link to be known.

In the case of implicit metrics, when using ARQ as an indicator for adaptation, the transmitter will need to make use of a considerable time when conditions demand the averaging of the whole information packet (i.e. when errors are presented all along the packet but not in bursts). The use of implicit SER based on the last received data, gives good information about the quality of reception; however it does not necessarily reflect the quality of reception at the other end of the link. Given this situation, implicit adaptation does not always achieve the expected performance improvement when conditions are non-reciprocal.

Explicit information enables the conditions at the other end of the link to be known to the transmitter. SER is calculated as normal and an indication is returned to the other node, thus allowing fast adaptation to the channel conditions to occur. However, there is an overhead in terms of signalling this information.

This paper presents simulation results obtained from a scenario where two devices are communicating under both homogeneous and heterogeneous interference conditions. A direct comparison of a system using implicit SER adaptation with one based on fast feedback explicit SER is presented. Both processes are complemented by the use of *Received Signal Strength Indication (RSSI)* at both ends of the link, in order to better specify the precise points for switching modulation schemes (DBPSK, DQPSK and 8DPSK are assumed in the simulations).

This work was supported by Toshiba Research Europe Ltd - TREL.
[1]Andrew Nix is with the Centre for Communications Research, University of Bristol, UK

II. UP AND DOWN ADAPTATION MODEL

The initial simulation comprises up and down adaptation (i.e. where channel conditions are improving and vice versa.) for a system using SER and RSSI as measurement metrics. The inclusion of RSSI is desirable to avoid use of an inappropriate modulation scheme, when the information given by SER is insufficient. For example, Fig. 2 shows the throughput of the simulated system in Additive White Gaussian Noise (AWGN). In the shadowed region, a system operating with DQPSK would exhibit a SER of zero, potentially indicating a change to 8PSK would be desirable when in fact throughput would be degraded. Inclusion of RSSI in the mode switch decision can alleviate this problem.

III. ALGORITHM IMPLEMENTATION

Specifications about the main characteristics of the developed simulator are presented in table 1. For packet transmission, a header is used in order to inform the receiver about the modulation format of the segments, packet identification plus other data related to control and adaptation. The header is always modulated and transmitted using the most robust scheme in the system (DBPSK).

The header is conformed by 64 bits plus a 24 bits long CRC (Cyclic Redundancy Check) frame for error detection. This frame is calculated by the same generator polynomial (degree 23) employed in the segments.

Each one of the 31 possible segments per packet is 1056 bits long (maximum), and it is conformed by an 8 bits long sequential number for identification, a maximum number of data bits of 1032 and 24 bits for CRC.

At the receiver, the *SER* for every segment is calculated. If errors are found in a segment after CRC checking, 1 will be stored in a temporary variable (0 otherwise). This information is then added for every packet and normalised to the total number of segments *k,* giving ERR_i.

$$ERR_i = \frac{\sum_{n=1}^{k} SER}{k} \qquad (1)$$

TABLE 1
SIMULATION PARAMETERS

Parameter	Mode 1	Mode 2	Mode 3
Modulation Scheme	π/2 DBPSK	π/4 DQPSK	D8PSK
Header Modulation	π/2 DBPSK	π/2 DBPSK	π/2 DBPSK
Maximum Bit Rate	4 Mbits/sec	8 Mbits/sec	12 Mbits/sec
Error Detection	CRC (Cyclic Redundancy Check)		
Error Correction	ARQ	ARQ	ARQ
Propagation model	Rayleigh	Rayleigh	Rayleigh
Bandwidth	4 MHz	4 MHz	4 MHz

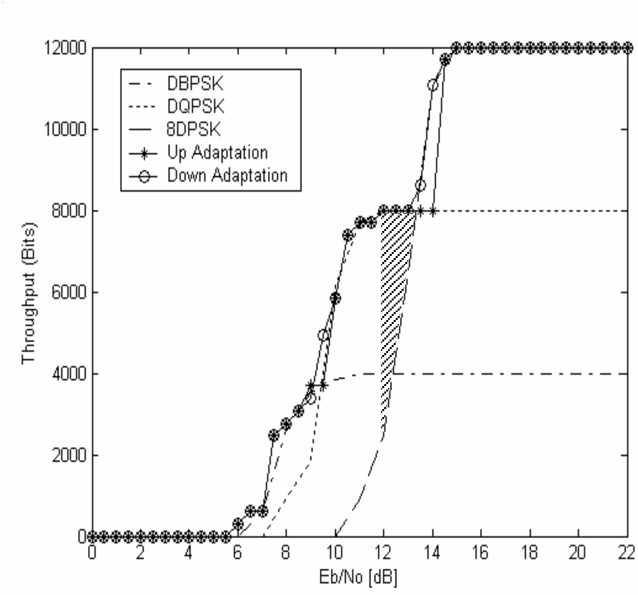


Fig. 2. Up and down adaptation in modulation.

Given that a desired threshold in throughput is expressed by *x* and RSSI by *R*, the bit to be fed back *(ERRr)* will have one of two possible values after direct comparison.

$$ERRr = \begin{cases} 0 & if \quad ERR_i < x \;\&\; RSSI < R \\ 1 & if \quad ERR_i \geq x \;\&\; RSSI \geq R \end{cases}$$

At the transmitter, the received values (ERR_r) are added and divided by the number of chosen packets *l* in order to get a decision *D* for adapting.

$$D = \frac{\sum_{n=1}^{l} ERR_r}{l} \qquad (2)$$

For the undertaken simulations, the relationship between modulation schemes is calculated according to the number of received bits. For instance, in table 2 the transition from DBPSK to DQPSK will be required only when more than 90% of the segments transmitted using BPSK in a packet have arrived correctly.

TABLE 2
ADAPTATION THRESHOLDS

Adaptation	Threshold	
	Normalised Throughput	RSSI
DBPSK → DQPSK	> 0.90 (DBPSK)	N/A
DQPSK → 8DPSK	> 0.90 (DQPSK)	> 14dB
8DPSK → DQPSK	< 0.72 (D8PSK)	N/A
DQPSK → DBPSK	< 0.50 (DQPSK)	N/A

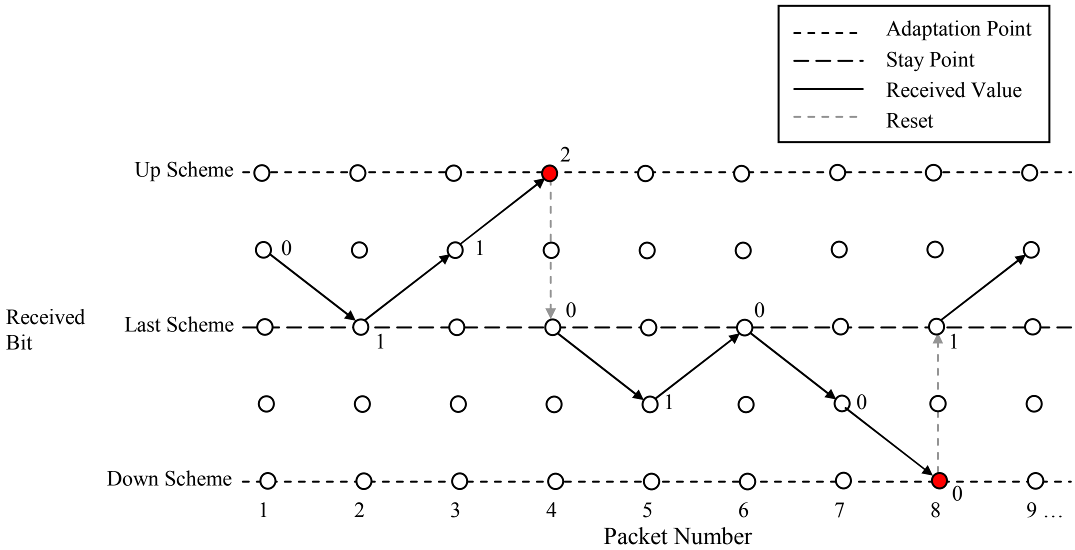


Fig. 3. Algorithm interpretation in time.

Fig. 3 represents the analysis of the bit used for the decision at the receiver in the simulations; where packet number indicates the received one, and received bit is the value of the bit that indicates the possible transition.

IV. DYNAMIC RESULTS

The tested model uses two packets (each one carrying a feedback bit) as means of information for adapting. In this case, if the adding of two consecutive bits is two, the system is informed to change to the upper modulation scheme available. When the adding is one, the system will remain transmitting using the last known configuration, and if the adding is zero the system will be required to transmit using the lower modulation scheme in order. The algorithm analyses only the bit from the last received packet in conjunction with its predecessor (earlier bits are discarded after adaptation or one by one after packet reception), thus taking into account the fast fading characteristics of the channel.

A. Interference Affecting two Terminals Homogeneously

Results in Fig. 4 show the throughput of the system for both terminals in two cases: when reciprocity was assumed (i.e. SER at the receiver is used for transmitter configuration) and when SER from the receiver is processed and then fed back to the transmitter. The throughput performance of the described algorithm shown to be equivalent to the response of the system assuming reciprocity, or only when local information is used for transmission.

In the mentioned figure, peaks or fluctuations in throughput occur when Eb/No is high and the result of interference plus desired signal overlaps the required RSSI threshold for adaptation from DQPSK to D8PSK. This makes the system assume it is an appropriate point for adapting to the next scheme when in reality it is somewhere in the shadowed region in Fig. 2.

B. Interference Affecting two Terminals Heterogeneously

Fig. 5 and 6 are the set of results in terms of throughput response when the interferer is moving towards one of the terminals, affecting the up and down links differently.

Results of the simulation are presented where both terminals start with a *Channel to Interference Ratio (CIR)* equivalent to 19 dB and this value starts incrementing in one link (up to 25 dB) and decrementing in the other (13 dB as minimum).

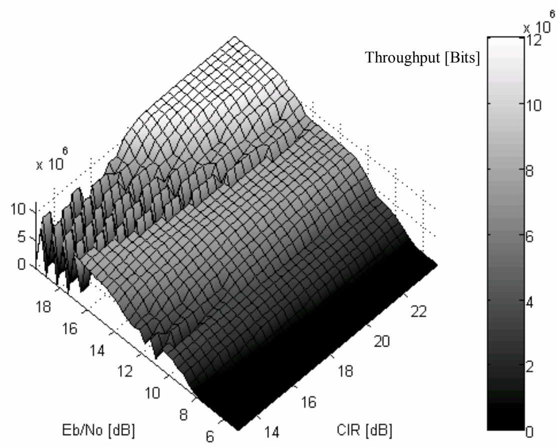
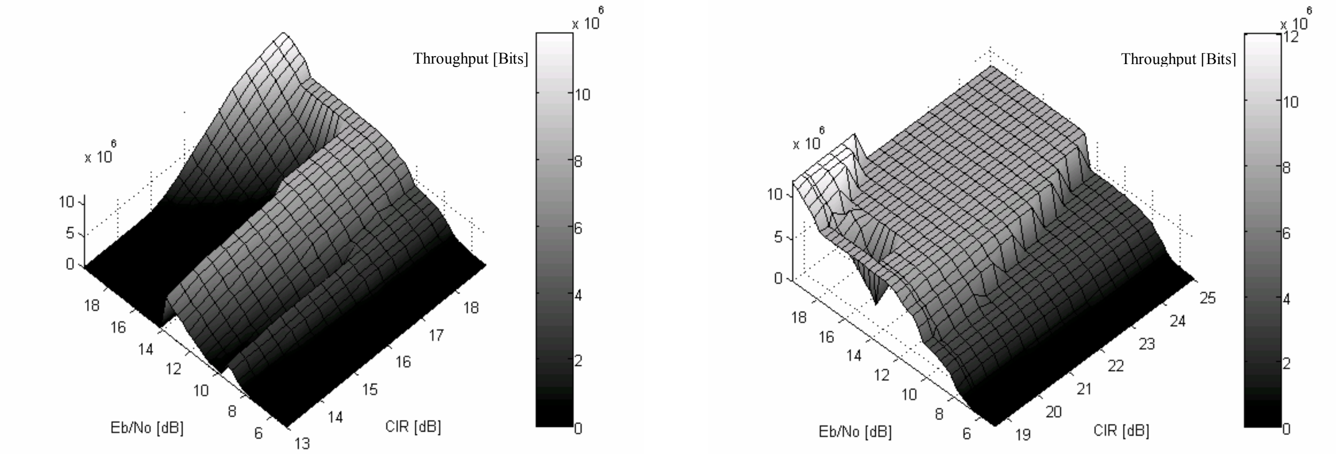


Fig. 4. Adaptation in the presence of increasing interference, equally distributed for both channels.

Fig. 5 shows the throughput response for the implicit SER and RSSI adaptation system (i.e. no feedback information) for terminals A and B. The results indicate that in a link assumed to be reciprocal, the only opportunity to adapt efficiently to 8DPSK is when interference is almost equal at both ends (in this case close to 19 dB). As the difference in the interference level between the ends of the link increases, the performance of the system deteriorates. This occurs as the node with lower interference believes that 8DPSK can be supported, this cannot be received at the node with higher interference. Since the 8DPSK packet will be received in error, the next packet to be sent from the higher interference node will use DQPSK. This packet will be received perfectly, so once again a packet will be sent back to the high interference node using D8PSK.

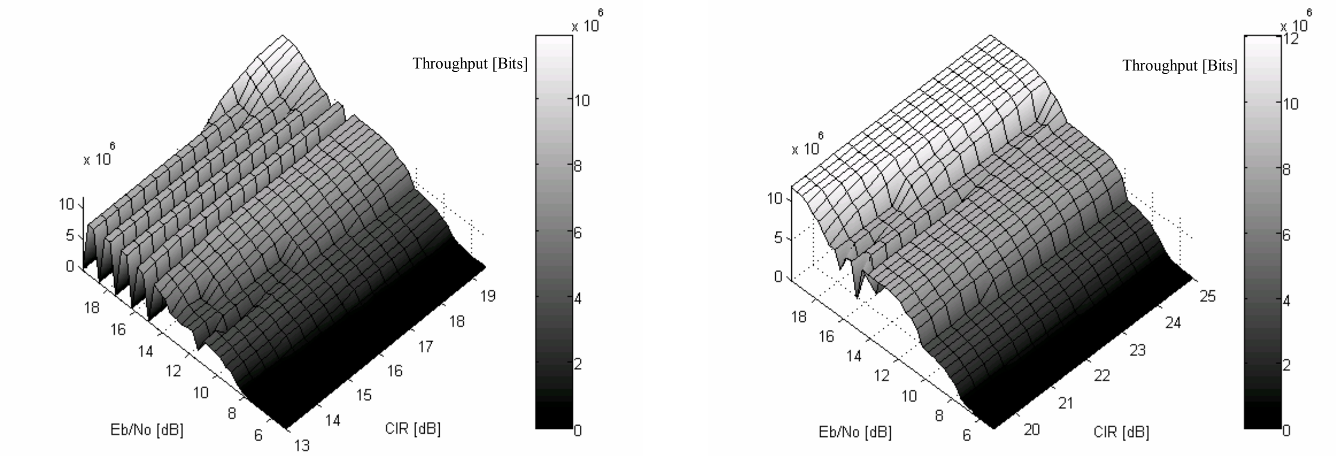
Under these conditions, the link from the high interference node to the low interference node will operate successfully, but not with the most efficient modulation mode. The link from the low interference node to the high interference node will continuously fail using this implicit algorithm.

Fig. 6 shows the throughput response of the system using the explicit feedback of the metric derived from SER and RSSI at the receiver. It can be concluded that in the presence of non-reciprocal interference, the performance is increased on *both* links, with adaptation occurring independently based on the reception quality at the other end of the link.



Terminal A Terminal B

Fig. 5. Adaptation in the presence of interference moving from centre to one terminal.



Terminal A Terminal B

Fig. 6: Adaptation in the presence of interference moving from centre to one terminal using one bit decision and RSSI.

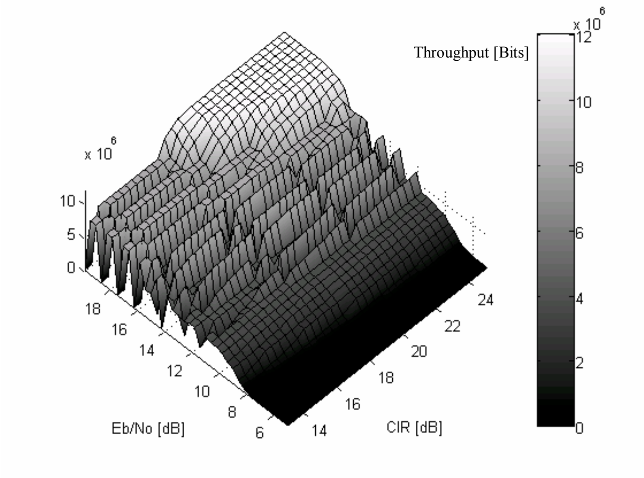


Fig. 7: Adaptation in the presence of interference moving from centre to one terminal using one bit decision and *no* RSSI.

Fig. 7 depicts the response of the algorithm when no RSSI is available at the receiver for *both* channels under heterogeneous interference. The no inclusion of RSSI drives the system to a poor performance when transmitting using DQPSK, as the point for changing modulation scheme is not well defined. As a result, there is an undesirable change to D8PSK when this scheme is presenting less performance in terms of throughput compared to the previous configuration.

It should be stressed that peaks in the response occur as the RSSI measured value is high due to the combination of the desired received signal plus interference. Thus, giving an unreal adapting optimum threshold as mentioned before.

V. CONCLUSIONS

In the presence of high or non-reciprocal levels of interference the performance of an adaptive modulation scheme is considerably degraded when not considering the non-homogeneous nature of the link.

When the proposed algorithm is used, the throughput is increased in both links. The performance which is exhibited is similar to that demonstrated when the channels followed independent adaptation profiles in the presence of non-reciprocal interference.

Further improvement in throughput can be achieved by measuring the RSSI at the receiver before sending data (e.g. in the guard period between packets) and then, during transmission. From this information, Interference Signal Strength Indication (ISSI) can be obtained and a more accurate switching point employed. Thus, reducing the risk of having loses of information due to the use of false adaptation points especially from DQPSK to D8PSK.

Upper layers can access and modify parameters for adaptation such as RSSI and Thresholds according to the Quality of Service (QoS) required. The inclusion of this approach makes the system more flexible as direct control of the data flow can be achieved. For instance, when high reliability in the transmitted information is required, a robust modulation scheme might be employed, and for links requiring a higher throughput regardless of some amount of errors, a modulation scheme conformed by the encoding of a bigger number of bits per period of time can be chosen.

ACKNOWLEDGMENT

The authors gratefully acknowledge the directors of Toshiba Research Europe Limited, Telecommunications Research Laboratory for their support and the permission to publish this work.

REFERENCES

[1] K. Balachandran, S. R. Kadaba and S. Nanda, "Channel Quality Estimation and Rate Adaptation for Cellular Mobile Radio," *IEEE J. Select. Areas Commun.,* vol. 17, pp. 1244-1256, July 1999.

[2] J. G. Proakis, *Digital Communications,* 3rd ed. New York, NY: McGraw Hill, 1995.

[3] A. J. Goldsmith and S. G. Chua, "Variable-Rate Variable-Power MQAM For Fading Channels," *IEEE Trans. Commun.,* vol. 45, pp. 1218–1230, October 1997.

[4] R. Taori, "Bluetooth Baseband Draft Specification" unpublished.