

# Link and system-level analysis of structured multi-hop networks

M. J. Hart and S. K. Vadgama

Fujitsu Laboratories of Europe Ltd, Hayes Park Central, Hayes, UK UB4 8FE

**Abstract** – The IST-ROMANTIK project focussed on resource management and advanced receiver architectures for multi-hop networks, running from February 2002 for 3 years. A modified UMTS HSDPA system level simulator incorporating relaying nodes was used to confirm gains predicted from a link level analysis of the propagation loss enhancement associated with the use of multi-hop techniques.

This paper provides a brief overview of the link level propagation analysis developed within the project. Whilst the link level interference analysis is not presented in this paper, system level simulation results are presented. In particular these indicate that for two specific deployment scenarios a significant increase in coverage, especially at the cell edge, as well as a capacity gain was achievable. However, these gains were shown to be dependent on both careful positioning of the relays and optimal setting of the transmit power.

**Index terms** – HSDPA, Multi-hop, System level simulation

## I. INTRODUCTION

The use of multi-hop relaying in both a structured and ad-hoc manner is currently attracting significant interest as a candidate solution for providing a cost-efficient mechanism for meeting the capacity and throughput demands of evolved and future wireless and mobile communication systems [1][2][3]. The investigation of multi-hop techniques, including structured and ad-hoc deployments with numerous relaying strategies was investigated within the IST-ROMANTIK project started in February 2002 and now in the process of finalisation.

This paper focuses mainly on the work conducted within the project by Fujitsu Laboratories of Europe, where the benefits of multi-hop techniques were examined from the point of view of a structured network along with development of radio resource management strategies. The work conducted used results from channel modelling performed by University of Bristol (UoB), UK and link level simulations by DUNE srl., Italy, both of which were project partners.

In order to develop an insight into the potential gain attributed to relaying, development of a link level analysis of a multi-hop network from the point of view of the effect on total propagation loss and interference was conducted. This was complemented by development of a structured multi-hop system level simulator based on an evolved UMTS HSDPA release 5 compliant simulator.

In summary, the system level simulator confirmed the findings of the link level analysis; indicating that both a

significant increase in user throughput is possible with an accompanying increase in system capacity.

This paper provides a brief overview of the detailed work presented in the project deliverables, including a propagation loss analysis of multi-hop networks and system level simulation results for two scenarios based on UMTS HSDPA indicated an average user throughput gain of 51% and 75%.

## II. PROPAGATION LOSS ANALYSIS

In general the total propagation loss is a combination of the pathloss, shadowing and multi-path diversity. It is necessary to consider the impact of all of these when examining the performance of multi-hop radio link techniques.

### A. Pathloss

A basic analysis of the pathloss, discussed in more detail in [4], highlights the potential gain available from multi-hop techniques. This arises when decomposition of a single link into two shorter links yields a reduction in the total pathloss. Figure 1 illustrates how the total pathloss varies with the location of the relay station (RS) and the difference between the distance of the direct and multi-hop link changes where the pathloss of any one link is given by [6]:

$$L = 15.3 + 37.6 \log r \quad (1)$$

Where  $r$  is the transmitter-receiver separation in metres, the constants arise from a carrier frequency of 2GHz and a transmit antenna height of 15 metres, the basestation (BS) to mobile station (MS) was fixed at 1.867km and  $s$  is a factor that indicates the path length extension factor when moving from the direct to relayed link.

In reality the pathloss parameters will be different for each link. Channel modelling conducted within the project by UoB found the parameters listed in Table I for the urban environment studied [5]. Also included are values obtained by adapting the model used in [6] for an RS antenna height of 5 metres.

Figure 2 illustrates the total pathloss for the channel models in Table I. Comparing with Figure 1 it is apparent that the region in which a reduction is experienced is reduced and that the optimal RS position is dependent on the parameters.

### B. Shadowing loss

A log-normal distribution is usually used to describe the shadowing induced variation in the pathloss. The model used in [6] assumes a constant standard deviation; however this is in conflict UoB's findings where a degree of distance dependency was observed [5].

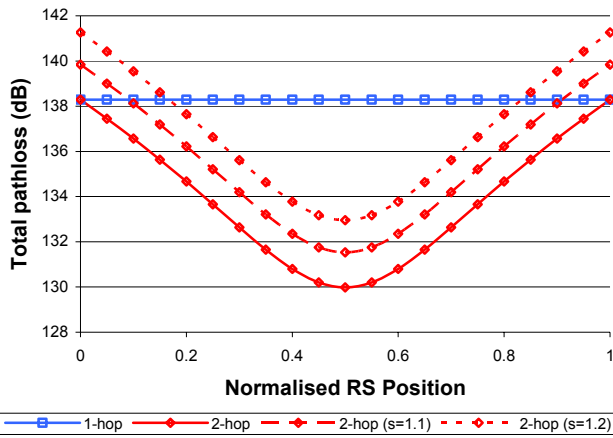


Figure 1. Total pathloss as a function of relative relay position and difference between direct and relayed path length for a BS to MS separation of 1.867km

TABLE I. PROPAGATION PARAMETERS[5].

Parameter	Link		
	NB-UE	NB-RN	RN-UE
b (dB)	15.3	15.5	28
N	3.76	3.68	4
b (dB)	13.07	16.29	10.04
N	4.88	4.64	5.47

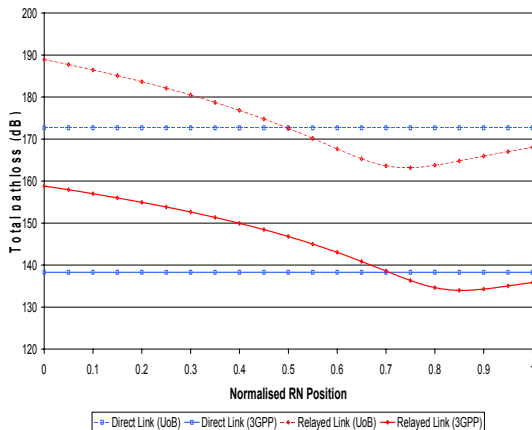


Figure 2. Total pathloss as a function of relative relay position for the two channel models in Table I.

Thus it can be expected that similar to the pathloss case, relaying will enable a reduction in the overall maximum shadowing loss. Further, careful positioning will enable coverage provision in areas of significant shadowing caused by obstructions (e.g. terrain or morphology/buildings in urban and rural). Two such scenarios are illustrated in Figure 3.

### C. Multi-path diversity

UoB's work indicated that the result of shorter links is a reduction in the multi-path RMS delay spread [5]. Whilst this could be viewed as a loss of diversity, it would mean that delay spread sensitive receiver architectures, such as the RAKE in multi-user W-CDMA, would experience improved signal to noise ratio performance.

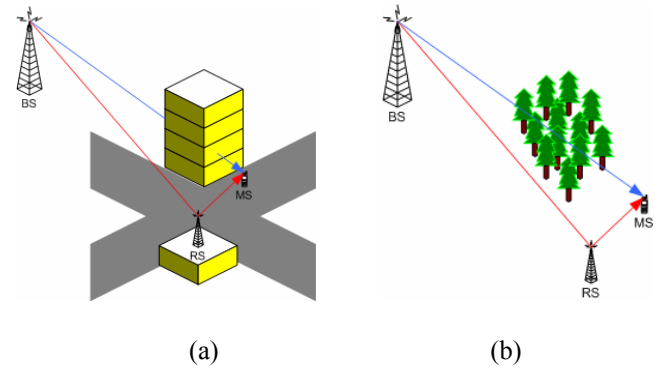


Figure 3. Use of relaying to reduce effect of shadowing in (a) urban and (b) rural environments.

### D. Summary

The pathloss and shadowing analysis indicated that with careful RS positioning, a reduction in the total propagation loss be achieved. This can translate into either a range extension for the same level of transmit power or provision of the same received signal strength for less total radiated power leading to the inference that in the cellular environment a reduction in interference will result.

Whilst a full interference analysis is not included here, this is presented in the project deliverable [4]. In summary, it indicated that interference reduction does result providing careful positioning and setting of the RS of the transmit power.

## III. SYSTEM SIMULATOR & PARAMETERS

System simulation was used to confirm the findings of the link level interference analysis and to indicate the typical gain that can be achieved if these techniques are adopted within a UMTS HSDPA network. The simulator consisted of 9, 3 sectored sites with 3 RS per sector. The interference calculation involved cell wrap around and considered transmissions from all the first tier neighbouring sectors.

Whilst many scenarios were considered, the results presented were generated from simulation using the parameters listed in Table II and given in [7] for the two deployment scenarios in Table III.

TABLE II. SIMULATION PARAMETERS.

Parameters	Value	
HS-DSCH power	Variable	
CPICH power	20% of total	
Antenna Pattern	120°	
HARQ scheme	Chase	
Base Station/ Relay Node	HS-DSCH/frame	15
	Relay buffer size	1.78 Mbits
	Ack/Nack Detection	Error free
	NB Scheduler	Round Robin
Relay type	Amplify & Forward	
RS/BS Duplexing	TDD	
HSDPA Category [8]	10	
Thermal Noise Density	-174 dBm/Hz	
User Equipment	Noise Figure	5dBm
	Detector	MMSE Equaliser
	Traffic Model	WWW [ref]
	Mobility	Semi-directed trajectory at 3kph

TABLE III. DEPLOYMENT SCENARIOS

Parameter	Scenario	
	1	2
Cell Radius	1867m	
Relay Position	933m	1400m

The RS and BS used the same carrier frequency in a TDD manner with the RS using an inter-TTI of 3 sub-frames to thus the RS did not perform simultaneous transmission and reception. Both the RS and UE utilised a low complexity spectral MMSE equaliser based on that developed by DUNE [9].

In all cases the number of users was fixed at 50 per sector as in the single hop case this resulting in the cell being fully loaded.

#### IV. RESULTS

Presented in this paper is a snapshot of the many detailed simulations conducted within the project, highlighting some of the key findings. Using the interference analysis developed within the project it was possible to determine the optimal setting of the BS and RS transmit power for the two deployment scenarios in order to maximise the received SINR in the region of the cell served by the RS. For each scenario, the results are summarised in Table IV.

Note in the relay case the total radiated power within one sector was set to such that it would not exceed 30dBm so that a fair comparison can be made with the case of no relays, as summarised in Table IV.

TABLE IV. SYSTEM SIMULATION RESULTS (AMPLIFY & FORWARD)

Scenario	Transmit Power (dBm)		System Throughput [7]		Utilisation Factor [7]	Average Packet Call Throughput	
	NB	RN	Mbps	Increase		kbps	Gain
-	9	-	1.4	-	99.2%	183	-
-	30	-	1.46	-	98.6%	220	-
1	1	25	1.55	6.2%	69.5%	332	51%
2	7	25	1.53	4.8%	68.9%	385	75%

Figure 4, 5 and 6 show the average packet call throughput experienced as a function of distance from the centre of the cell. For the single hop case it is shown that an increase in transmit power will not significantly increase the throughput, especially at the cell edge. This is because the throughput is interference limited, and hence increase in transmit power will not improve the observed signal to interference plus noise ratio (SINR). However, in the multi-hop case where an equal level of transmit power is radiated within one cell significant improvement in the average packet call throughput can be achieved.

Figure 4 indicates that the variation in average packet call throughput across the cell is greatly increased with the users close to the cell site in general connecting directly to the BS and those beyond the RS position connecting to the RS. The variation is due impart to the fact that the loading, indicated by the utilisation factor in Table IV, is significantly reduced and thus results in the change in throughput profile; a similar effect is experienced in the single hop case when the loading is reduced.

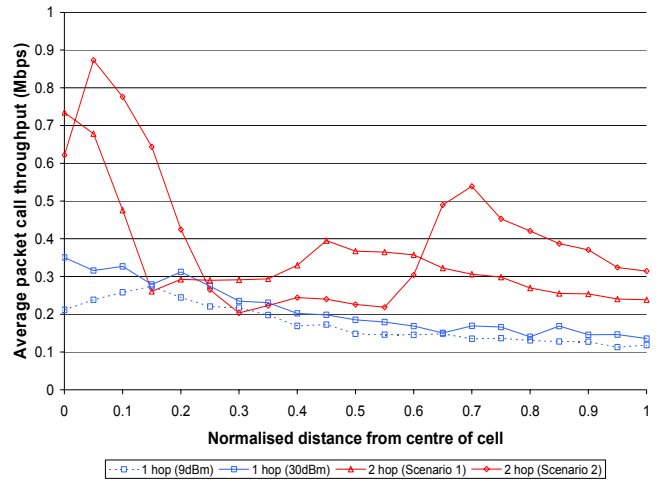


Figure 4. Average packet call throughput as a function of the normalised distance from the centre of the cell.

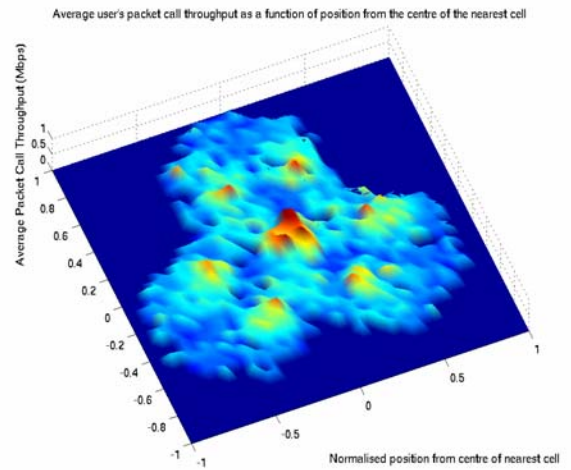


Figure 5. Average packet call throughput as a function of position in the cell for scenario 1.

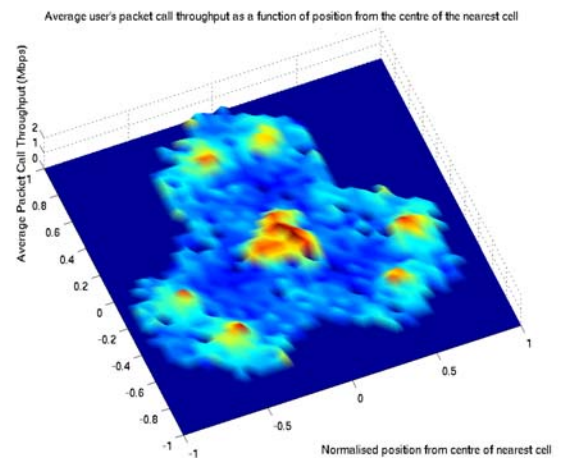


Figure 6. Average packet call throughput as a function of position in the cell for scenario 2.

It is also apparent from Figure 4 that there is a region where the throughput is not significantly increased beyond that available in the single hop case. This region is in general just behind the RS and is caused by a combination of the fact that a fixed transmit power is used at the BS for all transmissions, whether to a UE or RS, and the difference in antenna height between a RS and UE resulting in the pathloss exponent being greater for the UE. The net result is that a UE located in the vicinity of the RS will experience a reduced signal power level compared to that at the RS.

It is possible to increase the BS transmit power, initially set to optimise the SINR in the coverage area of the RS, to compensate for this. However this will cause increased interference to the RS transmissions from the BS due to the fact that TDD is used. The impact of increasing the BS transmit power is indicated by the results presented in Figure 7 where it is clearly shown that as the BS transmit power is increased, then the throughput is improved behind the RS but this is at the expense of the throughput within the region of the RS due to the fact this will reduce the received SINR.

In summary, it was found that it was possible to increase the average packet call throughput by 51% and 75% for the two deployment scenarios without an increase in overall transmit power. Coupled with this a reduction in the utilisation factor was experienced indicating that the loading of the cell was significantly reduced even though the number of users and traffic demands of each were unchanged between simulation scenarios.

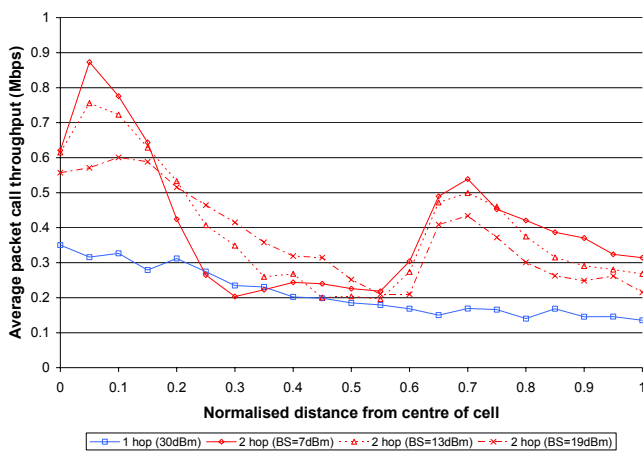


Figure 7. Average packet call throughput as a function of distance from the cell site for relay deployment scenario 2 for a fixed RS transmit power of 25dBm.

## V. CONCLUSIONS

A link level analysis of the impact on the total propagation loss experienced between a source and a destination node in a wireless communication system incorporating multi-hop techniques indicated that providing RS's are carefully positioned a reduction should be experienced.

It was inferred that in the cellular environment this reduction in propagation loss could translate either to an extension in

range or a reduction in required transmit power consequently reducing the level of interference experienced.

Within the ROMANTIK project an in-depth interference analysis was performed at the link level, indicating that providing RS's are carefully positioned and the transmit power of the RS and BS is configured in an optimal manner then improvement in the received SINR in the area covered by the RS will be experienced.

Finally, system simulation was used to confirm this analysis and to determine for the case of UMTS HSDPA the achievable throughput gain by incorporating RS's. It was found for two specific deployment scenarios that a gain in the average packet call throughput of 50% and 75% was achievable. This was coupled with a reduction in the observed utilisation factor indicating a reduction in the effective loading which indicates an increase in available capacity.

In conclusion, it has been shown at both the link and system level that it is possible to use multi-hop techniques to improve throughput and capacity, particularly in a UMTS HSDPA network.

## ACKNOWLEDGEMENTS

This work was conducted as part of the IST fifth framework project ROMANTIK. The authors would like to thank all project partners involved for their co-operation.

## REFERENCES

- [1] Lott, M., et al, "Hierarchical Cellular Multihop Networks", EEMPC, pp. 37-43, 2003.
- [2] Fujiwara, A., et al, "Area Coverage and Capacity Enhancement by Multihop Connection of CDMA Cellular Network", IEEE, 2002
- [3] Documents from the 3GPP-TSG-RAN UTRAN Evolution Workshop, Toronto, Canada November 2004 ([ftp://ftp.3gpp.org/workshop/2004\\_11\\_RAN\\_Future\\_Evo/](ftp://ftp.3gpp.org/workshop/2004_11_RAN_Future_Evo/)).
- [4] Hart, M., Vadgama, S., "Benefit of multihop network operation with advanced antenna techniques", IST-ROMANTIK Deliverable D311, April 2005.
- [5] Wang, J., et al., "Microcell Channel Models for Multi-Hop Relaying in the 2GHz and 5GHz Band", IST-ROMANTIK Deliverable D323, October 2003.
- [6] 3GPP, "Selection procedures for the choice of radio transmission technologies of the UMTS", TR101.112 (UMTS30.03), 1998.
- [7] 3GPP-TSG-RAN, "Physical layer aspects of UTRA High Speed Downlink Packet Access", TR25.848, v4.0.0, 2001.
- [8] 3GPP-TSG-RAN, "UE Radio Access Capabilities", TS25.306, Release 5, 2003.
- [9] de Marinis, E., Gasparini, O., Hart, M., "A general purpose low-complexity spectral equaliser for 3G and 4G systems not requiring a cyclic prefix", Accepted for publication in IST Mobile Communications Summit, May 2005.