IST-2000-30148 I-METRA

D6.2

Implications in Re-configurable Systems beyond 3G (Part2)

Contractual Date of Delivery to the CEC:	**31 August, 2003**
Actual Date of Delivery to the CEC:	**31 October, 2003**
Author(s):	**Javier R. Fonollosa, Alba Pagès-Zamora, Oumer Teyeb**
Participant(s):	**AAU, UPC**
Work package:	**WP6: Implications in Re-configurable Systems beyond 3G**
Est. person months:	**6**
Security:	**Public**
Nature:	**Report**
Version:	**1.0**
Total number of pages:	**34**

Abstract:

This activity evaluates the extension of the bandwidth of the UTRA MIMO HSDPA concept to 20 MHz, which is precisely the bandwidth of HIPERLAN/2. This would allow a fair comparison between the performance of UTRA MIMO HSDPA and the enhanced HIPERLAN/2. The bandwidth expansion would be the consequence of multiplying the chip rate of the W-CDMA spreading by four, i.e., 3.84 x 4 = 15.36 Mcps. A higher bandwidth MIMO channel model is necessary and this will be developed based on the channel model already developed in WP2.

High data rates are required to satisfy the ever-increasing application requirements in future wireless communication systems. Recent investigations have indicated that a peak data rate of up to 20Mbps per user in the DL may be required for satisfactory reception of bursty traffic. As the transmission powers (of both mobile terminals and base stations) are limited, higher data rates lead to the reduction of the effective coverage area of a cell. That is, only users that are close to the base station will be able to communicate with high data rates, while users far away from the base station will only be able to use low data rates.

Keyword list: UMTS, MIMO, HSDPA, ODMA, HIPERLAN/2,

EXECUTIVE SUMMARY

Two different subtasks were planned for this deliverable.

The first sub-task evaluates the extension of the bandwidth of the UTRA MIMO HSDPA concept to 20 MHz, which is precisely the bandwidth of HIPERLAN/2. This would allow a fair comparison between the performance of UTRA MIMO HSDPA and the enhanced HIPERLAN/2. The bandwidth expansion would be the consequence of multiplying the chip rate of the W-CDMA spreading by four, i.e., 3.84 x 4 = 15.36 Mcps. A higher bandwidth MIMO channel model is necessary and this will be developed based on the channel model already developed in WP2.

In the second sub-task, the rationale behind using multihop cellular networks will be presented first, followed by a description of ODMA, which is a procedure developed to support multihopping. There is a large body of research related to the investigation of multihop networks, and the next section is a review of some research papers in the area. Finally, some issues that have to be considered in order to make multihop cellular networks a reality will be presented.

DISCLAIMER

1 INTRODUCTION

This document and Deliverable D6.1 [31] complete WP6. As described in the I-METRA Annex 1, Wokpackage WP6 *should try to answer the following generic questions: What are the challenges for implementing MIMO in each of the scenarios envisioned for Systems Beyond 3G (SB3G)? What are the alternative enabling technologies and how does their performance compare?* Two different subtasks were planned for this deliverable:

- Task 2.a. Potential extension of HSDPA to higher bandwidth
- Task 2.b Comparison with multihop concepts.

The first sub-task evaluates the extension of the bandwidth of the UTRA MIMO HSDPA concept to 20 MHz, which is precisely the bandwidth of HIPERLAN/2. This would allow a fair comparison between the performance of UTRA MIMO HSDPA and the enhanced HIPERLAN/2. The bandwidth expansion would be the consequence of multiplying the chip rate of the W-CDMA spreading by four, i.e., 3.84 x 4 = 15.36 Mcps. A higher bandwidth MIMO channel model is necessary and this will be developed based on the channel model already developed in WP2.

The second sub-task deals with multihop concepts. High data rates are required to satisfy the ever-increasing application requirements in future wireless communication systems. Recent investigations have indicated that a peak data rate of up to 20Mbps per user in the DL may be required for satisfactory reception of bursty traffic [1]. As the transmission powers (of both mobile terminals and base stations) are limited, higher data rates lead to the reduction of the effective coverage area of a cell. That is, only users that are close to the base station will be able to communicate with high data rates, while users far away from the base station will only be able to use low data rates.

A simple solution to this problem would be to decrease the cell area and increase the base station density. However, this solution is not economically feasible. By using different propagation models, [1] have shown that quasi line-of-sight deployments lead to a more acceptable data rate compared with non line-of-sight models. This indicates that a multihop cellular architecture, where there is a possibility of peer-to-peer communication or communication that is relayed via other terminals or fixed relays, can be an economically feasible solution to the data rate vs. coverage trade off problem. Recent studies have indicated that there is indeed a performance improvement, especially in terms of coverage enhancement, in using multihop extensions.

In this sub-task, the rationale behind using multihop cellular networks will be presented first, followed by a description of ODMA, which is a procedure developed to support multihopping. There is a large body of research related to the investigation of multihop networks, and the next section is a review of some research papers in the area. Finally, some issues that have to be considered in order to make multihop cellular networks a reality will be presented.

2 POTENTIAL EXTENSION OF HSDPA TO HIGHER BANDWIDTHS

The main objective of this task is to compare the I-METRA link-level results with results of other IST project results under similar conditions of channel bandwidth, carrier frequency and channel scenarios. Specifically, it is planned to compare the HSDPA I-METRA results for UMTS with results for HYPERLAN/2 obtained by other projects. This ambitious objective entails two different steps:

- The extension of the MIMO channel model to a higher bandwidth of 20MHz and a carrier frequency of 5 GHz.
- Search of common scenarios and configurations tested by other projects in order to be able to make a fair comparison.

Specifically, link-level results will be obtained with the extended bandwidth MIMO channel for the system structure defined in D3.2 “Implementation of Relevant Algorithms” [32] that combines linear dispersion codes at the transmitter side with a turbo space-time multicode detector at the receiver. Thus, the chip rate will be increased by 4 and the TTI length reduced by 4 (that is, 15.36 Mcps and 500 μs of TTI). The spreading factor will be kept equal to 16. In consequence, the bit rates specified in D4 “Performance Evaluation” [33] will be directly multiplied by a factor of 4 for the extended bandwidth MIMO channel model.

The results of the search for common scenarios and configurations tested by other projects was included in [31]. It was concluded that I-METRA results for a 20MHz extended bandwidth channel model were suitable to compare with results of ROMANTIK, MATRICE and FITNESS IST projects. The following table summarises the basic link simulation parameters agreed between the projects during the second BAI cluster meeting that took place on March 12th 2003.

Common Scenario	I-METRA	MATRICE	FITNESS	ROMANTIK
Targeted standard	UMTS++	4G Cellular	UMTS++	UMTS++
Objectives	Throughput vs Range	Throughput	Reconfigurability	Throughput & Reconfigurability
Frequency	2 & 5 GHz	5 GHz	2 & 5 GHz	2 & 5 GHz
Bandwidth	5 & 20 MHz	50 MHz	5 MHz	5 & 20 MHz
Type of service	Packet	Packet	Packet	Packet
Max User Bit Rate	40 Mbps	50 Mbps	20 Mbps	40 Mbps
Max No of antennas	4x4	to be run	4x4	4x4
Mobility (Indoor/Outdoor) (Min-Max km/h)	3(O)-120(O)-300(O)	3(I)-300(O)	3(O)-120(O)	3(I&O)-50 (O)
UL/DL	UL/DL	UL/DL	DL	UL/DL
Duplex	FDD	TDD	FDD	FDD & TDD
Channel models	I-METRA	3GPP2/LT	3GPP1/3 (Geometry based stochastic)	TBC
HW platform	NO	YES (BB, TI DSP, XILINX FPGAs)	YES (RF & BB)	NO

Table 1. Parameters agreed for simulation harmonisation.

The comparison framework between I-METRA and FITNESS has been further detailed. The following table summarises the basic simulation parameters agreed by both projects to compare their respective results in future BAI cluster meetings.

Project	**FITNESS**	**I-METRA (20 MHz)**
MIMO Configuration	2x2, 4x4, other	2x1, 2x2
Gross bit rates	6,12,24,36,54 Mbps	9.6, 19.6 Mbps
Coding type	½ and ¾ Convolutional	½ Turbo
Modulation	BPSK, QPSK	QPSK, 16QAM
Packet length	864	5114 bits
Packet duration	≤ 72 μs	~ 2ms/4 = 500 μs
Channel model	Close to ETSI BRAN C and E at 1.8 and 3 Km/h	ETSI BRAN A, C, D and E at 3 Km/h

Table 2. Basic link simulation parameters of FITNESS HYPERLAN/2 and I-METRA HSDPA 20 MHz extension.

This degree of detail is not available for other projects such as ROMANTIK or MATRICE since they have not defined their simulation scenarios in the context of the BAI cluster yet. Therefore, the comparison framework is constrained to the general parameters included in Table 1.

2.1 Link Level I-METRA Results

Although the I-METRA contract expired on August 31st 2003 UPC plans to continue activities related to this WP in the context of the BAI cluster until December 2003.

Taking into account the harmonization parameters of Table 1 and Table 2, I-METRA plans to obtain results for two different schemes: the Alamouti scheme for the 2x1 MIMO configuration and the V-BLAST scheme for a 2x2 MIMO configuration. The simulation results for 3km/h will be suitable to compare to FITNESS results, whereas simulation results for 300km/h are specifically for the MATRICE project. Table 3 includes the simulations I-METRA is planning to run for the 20MHz extended bandwidth channel model.

	CHANNEL MODEL	ALAMOUTI 2x1	V-BLAST 2x2
3 km/h	ETSI BRAN A	✔	✔
	ETSI BRAN C	✔	✔
	ETSI BRAN E	✔	✔
	ETSI BRAN D	✔	✔
300 km/h	ETSI BRAN E	✔	
	ETSI BRAN D	✔	✔

Table 3. Scenarios run (or planned to be run) by I-METRA for the 20MHz enlarged bandwidth system.

This deliverable includes the results of the Alamouti 2x1 scheme. UPC expects to have the rest of results of Table 3 by the beginning of December, ready to be presented in the BAI cluster meeting to be held in December 9th 2003.

2.2 Simulation Results

Computer simulations have been carried out to analyze the system structure defined in D3.2 "Implementation of Relevant Algorithms" [32] that combines linear dispersion codes at the transmitter side with a turbo space-time multicode detector at the receiver but now with the 20MHz extended bandwidth MIMO channel. Thus, the chip rate will be increased by 4 and the TTI length reduced by 4 (that is, 15.36 Mcps and 500 μs of TTI). The spreading factor will be kept equal to 16. In consequence, the bit rates specified in D4 "Performance Evaluation" will be directly multiplied by a factor of 4 for the extended bandwidth MIMO channel model. It is also important to remark that this system assumes perfect channel knowledge at the receiver.

The performance is analysed in terms of the TTI error rate vs EbNo as it was justified in deliverable D4 "Performance Evaluation" [33]. A detailed definition of the EbNo metric can be found in [33].

Simulation Results Alamouti 2x1 at 3km/h

The following figures illustrate results for the Alamouti scheme for the channel models of the ETSI BRAN A, C, D and E for 3km/h channel. Specifically, two different data rates of 9.6 Mbps and 19.6 Mbps are shown for the Alamouti 2x1 scheme with 10 codes, coding rate of 0.5 and QPSK or 16QAM modulations. We include both the TTI Error rate versus the EbNo and throughput results.

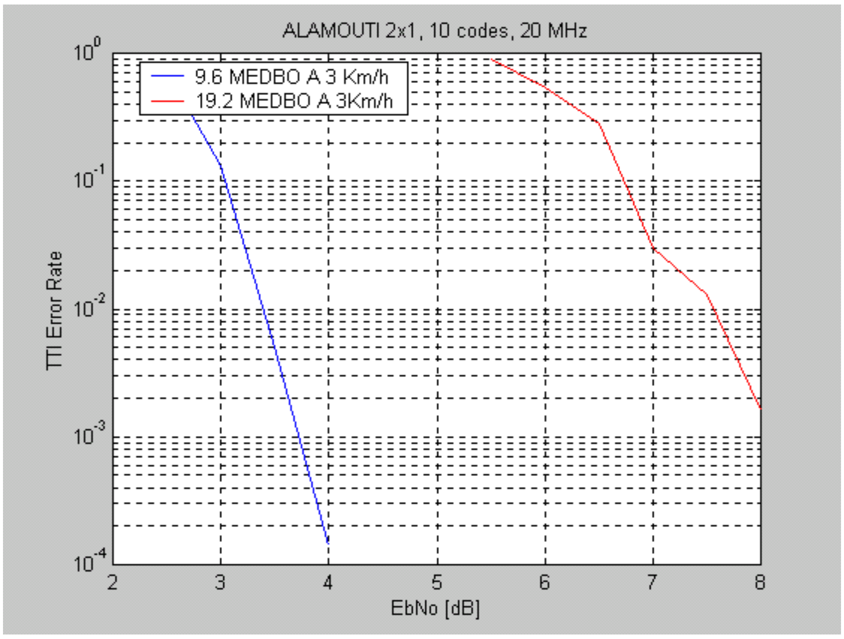


Figure 1. TTI Error Rate versus EbNo for Alamouti 2x1 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN A channel at 3Km/h.

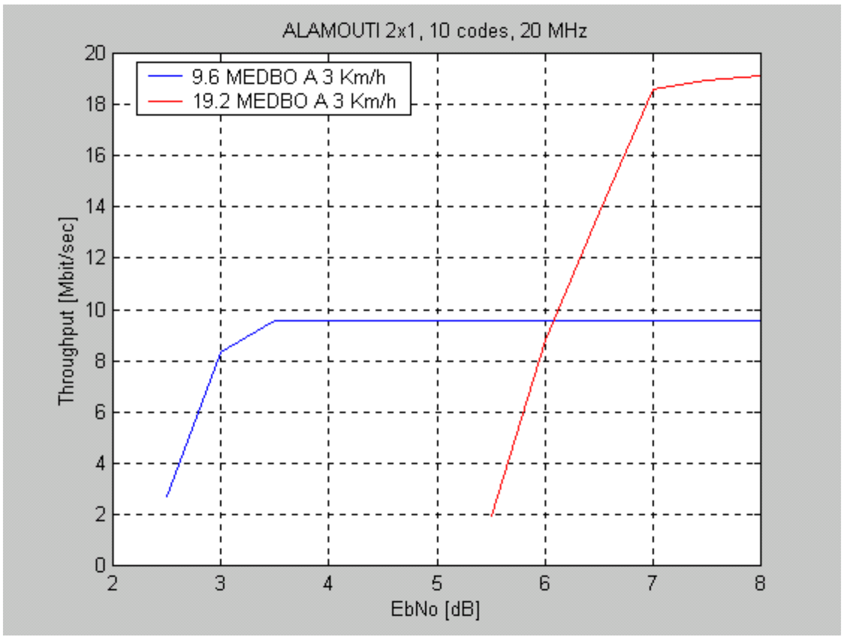


Figure 2. Throughput versus EbNo for Alamouti 2x1 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN A channel at 3Km/h.

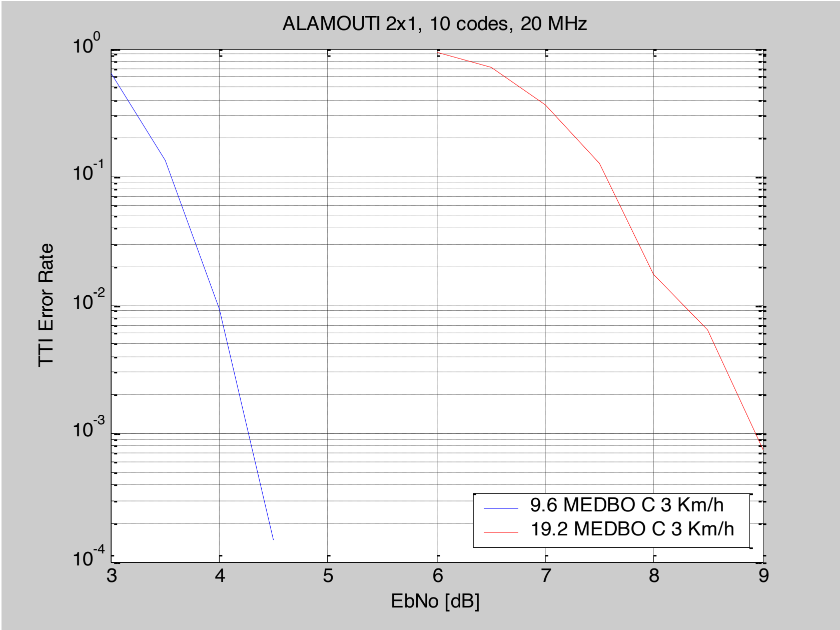


Figure 3. TTI Error Rate versus EbNo for Alamouti 2x1 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN C channel at 3Km/h.

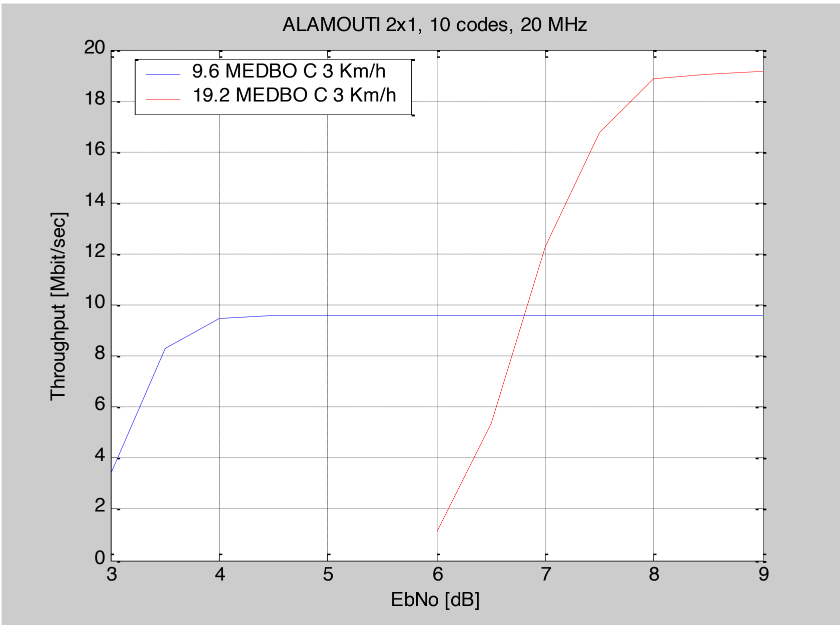


Figure 4. Throughput versus EbNo for Alamouti 2x1 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN C channel at 3Km/h.

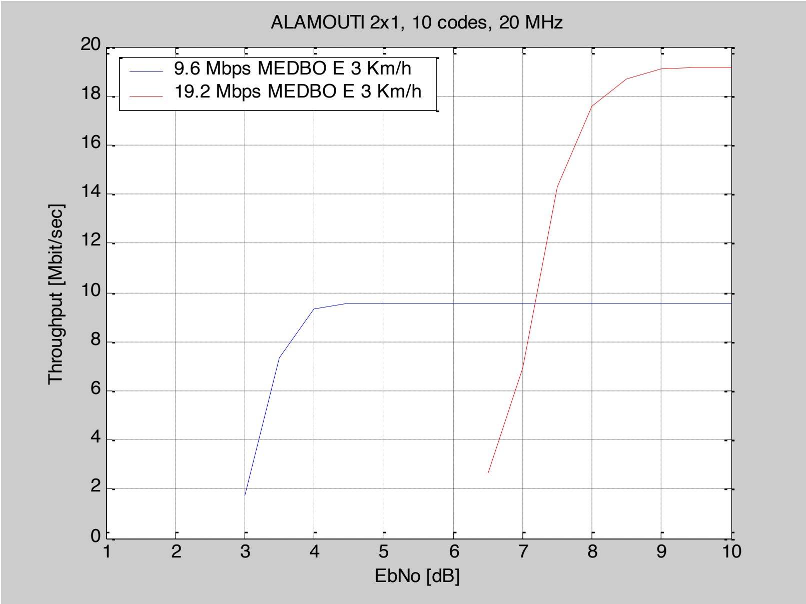


Figure 5. TTI Error Rate versus EbNo for Alamouti 2x1 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN E channel at 3Km/h.

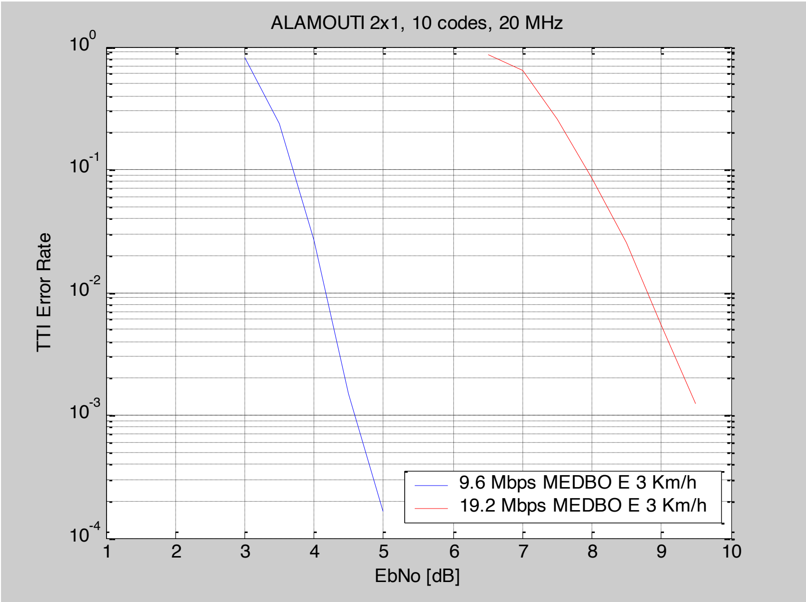


Figure 6. Throughput versus EbNo for Alamouti 2x1 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN E channel at 3Km/h.

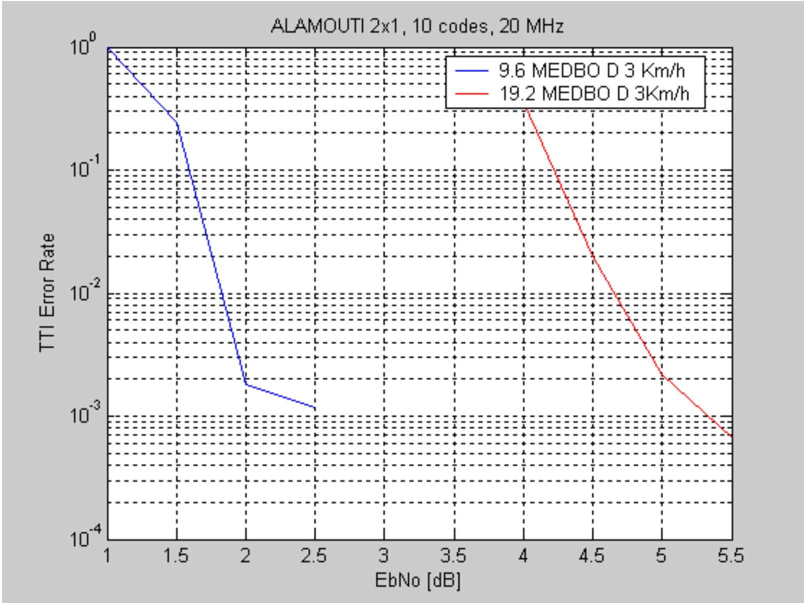


Figure 7. TTI Error Rate versus EbNo for Alamouti 2x1 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN D channel at 3Km/h.

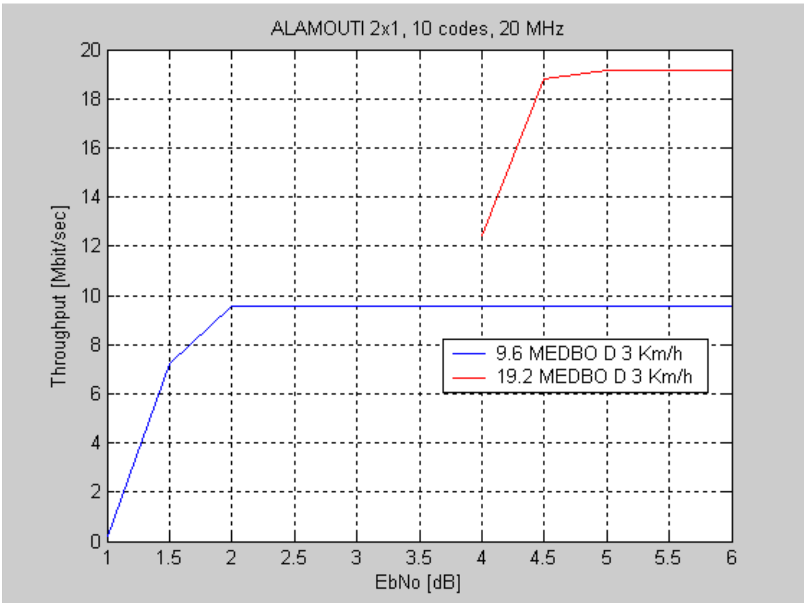


Figure 8. Throughput versus EbNo for Alamouti 2x1 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN D channel at 3Km/h.

Simulation Results Alamouti 2x1 at 300km/h

The following figures illustrate results for the Alamouti scheme for the channel models of the ETSI BRAN D and E for 300km/h channel. Specifically, two different data rates of 9.6Mbps and 19.6 Mbps are shown for the Alamouti 2x1 scheme with 10 codes, coding rate of 0.5 and QPSK or 16QAM modulations. Alternatively, we show the TTI Error rate versus the EbNo and throughput results.

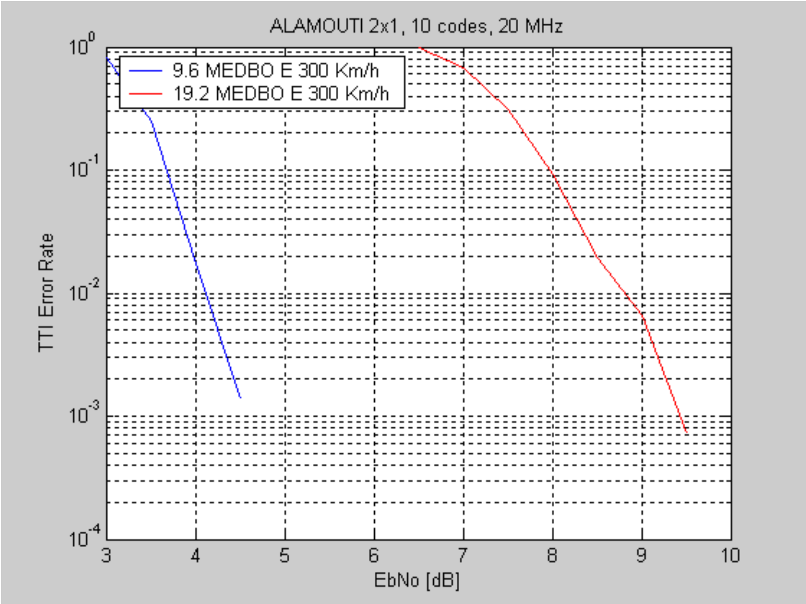


Figure 9. TTI Error Rate versus EbNo for Alamouti 2x1 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN E channel at 300Km/h.

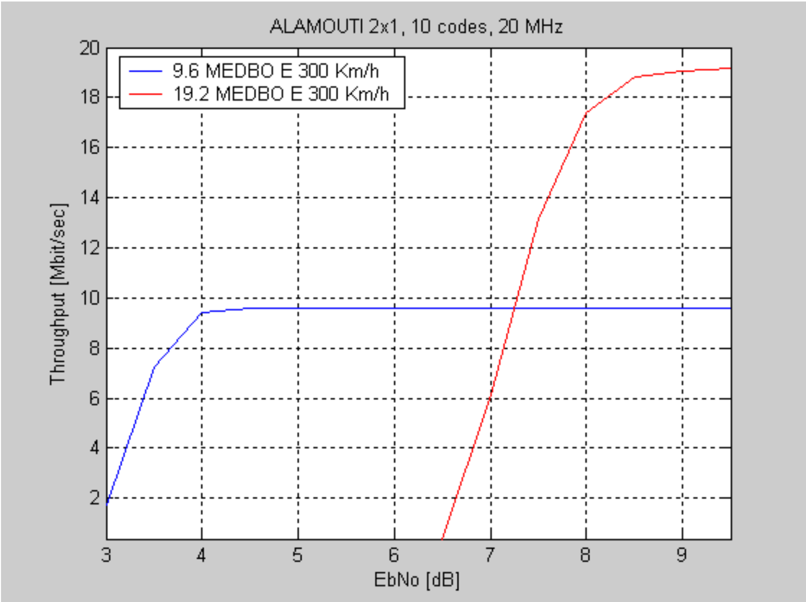


Figure 10. Throughput versus EbNo for Alamouti 2x1 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN E channel at 300Km/h.

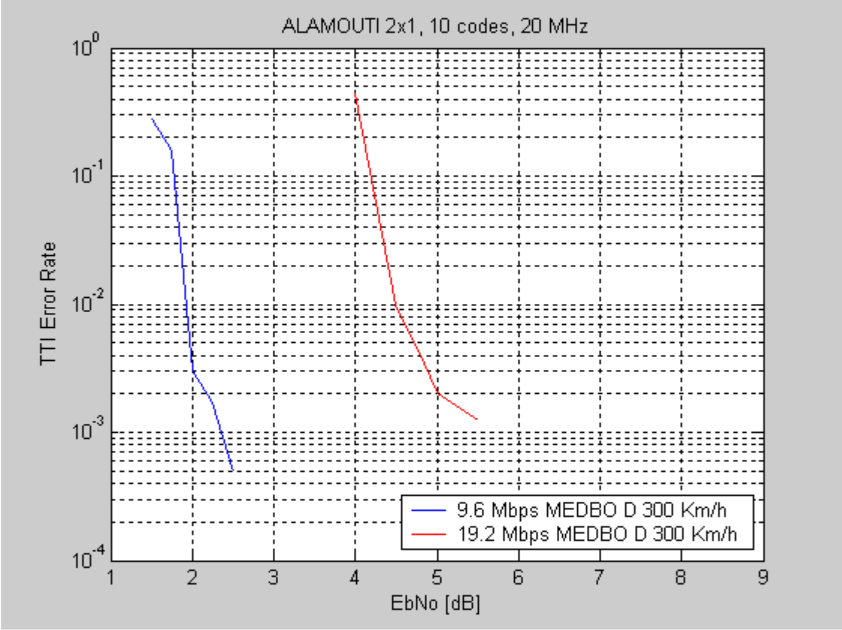


Figure 11. TTI Error Rate versus EbNo for Alamouti 2x1 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN D channel at 300Km/h.

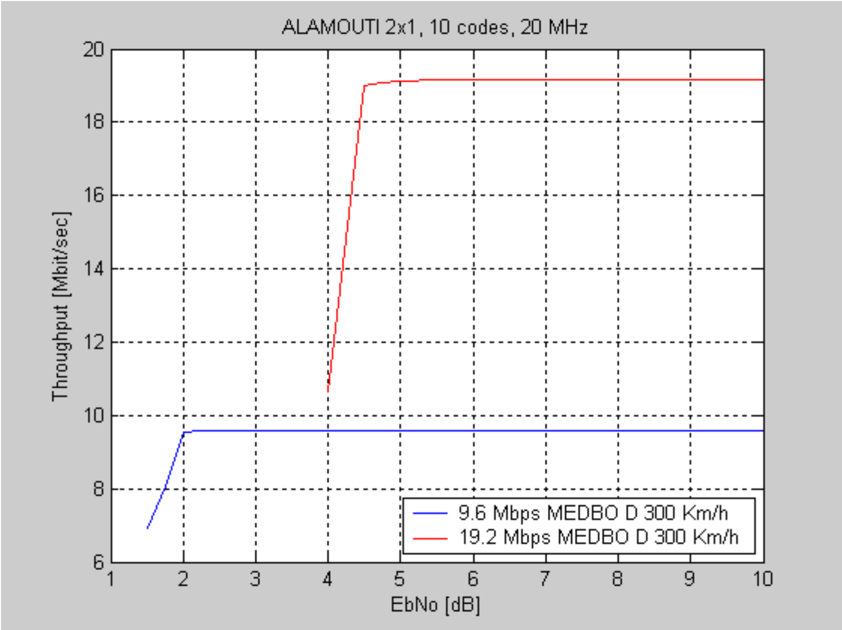


Figure 12. Throughput versus EbNo for Alamouti 2x1 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN D channel at 300Km/h.

Simulation Results V-BLAST 2x2 at 3km/h

The following figures illustrate results for the V-BLAST scheme with 2 antennas both at the receiver and transmitter side for the channel models of the ETSI BRAN A, C, D and E for 3km/h channel. Specifically, two different data rates of 19.2 Mbps and 38.4

Mbps are shown for the V-BLAST 2x2 scheme with 10 codes, coding rate of 0.5 and QPSK or 16QAM modulations. We include both the TTI Error rate versus the EbNo and throughput results.

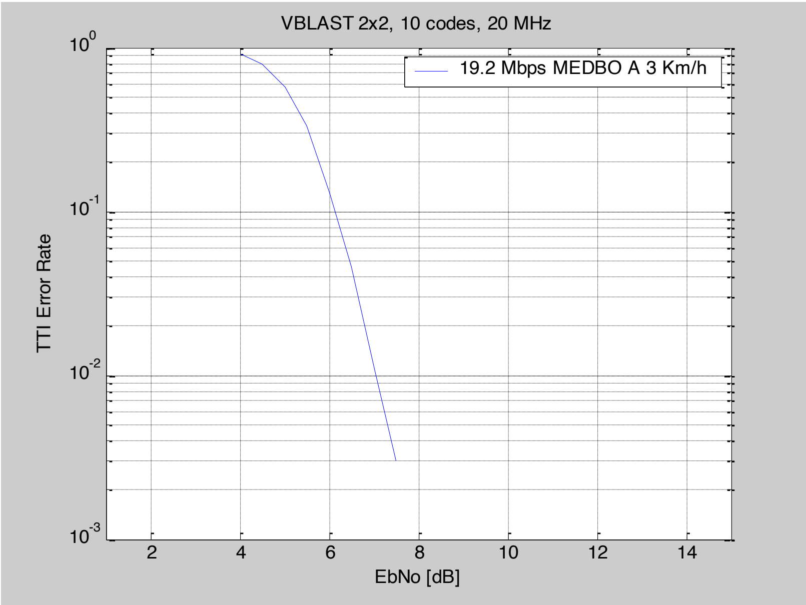


Figure 13. TTI Error Rate versus EbNo for V-BLAST 2x2 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN A channel at 3Km/h.

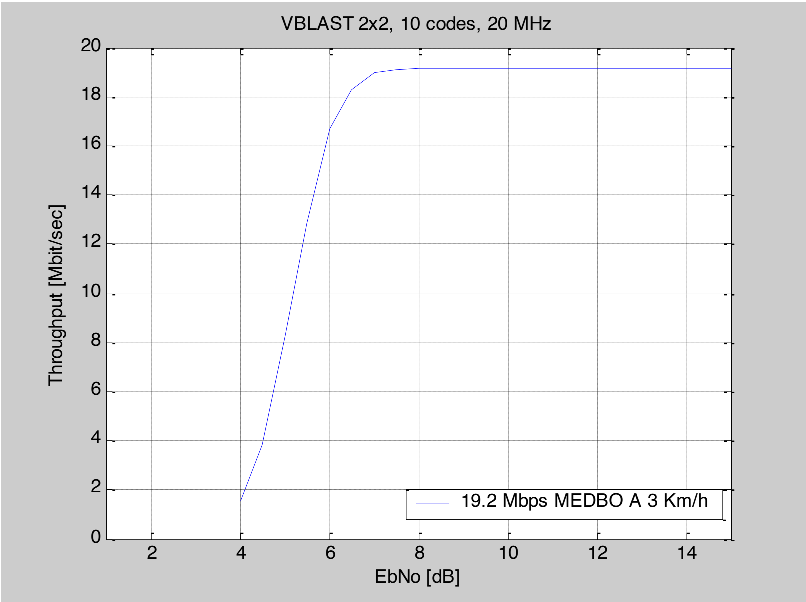


Figure 14. Throughput versus EbNo for V-BLAST 2x2 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN A channel at 3Km/h.

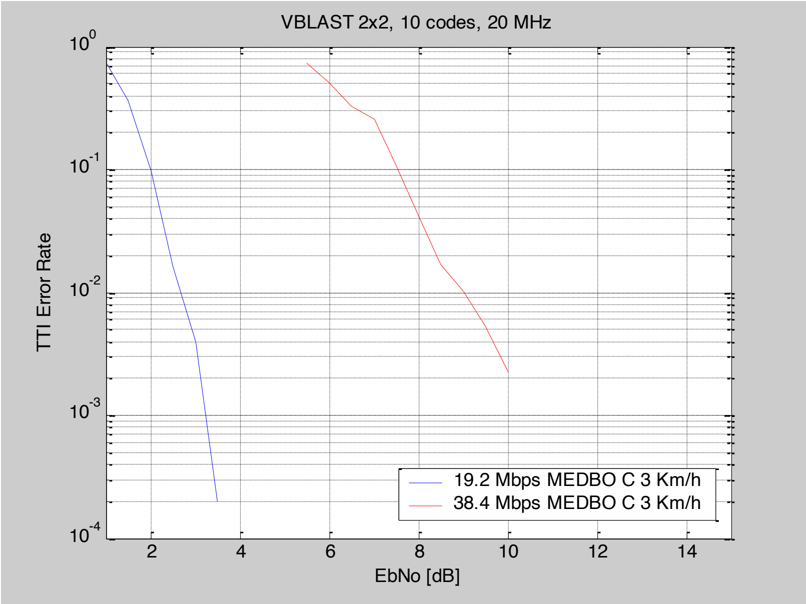


Figure 15. TTI Error Rate versus EbNo for V-BLAST 2x2 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN C channel at 3Km/h.

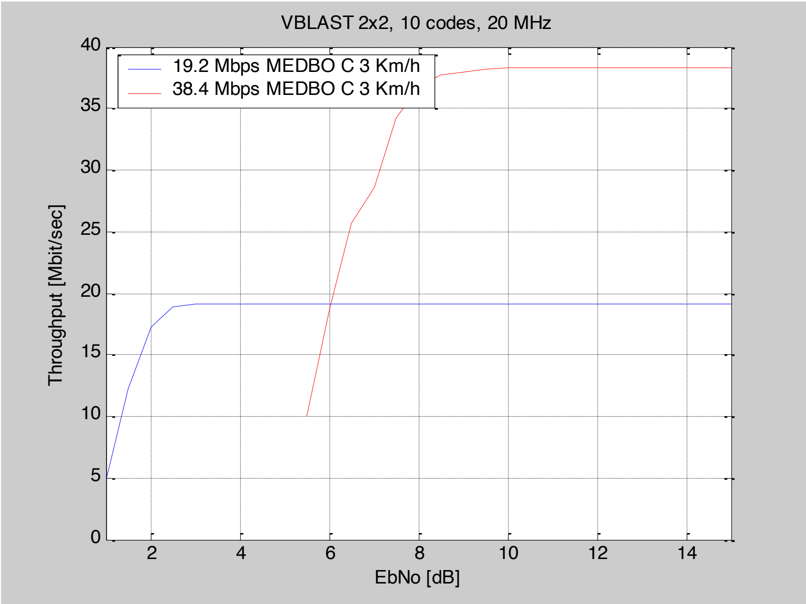


Figure 16. Throughput versus EbNo for V-BLAST 2x2 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN C channel at 3Km/h.

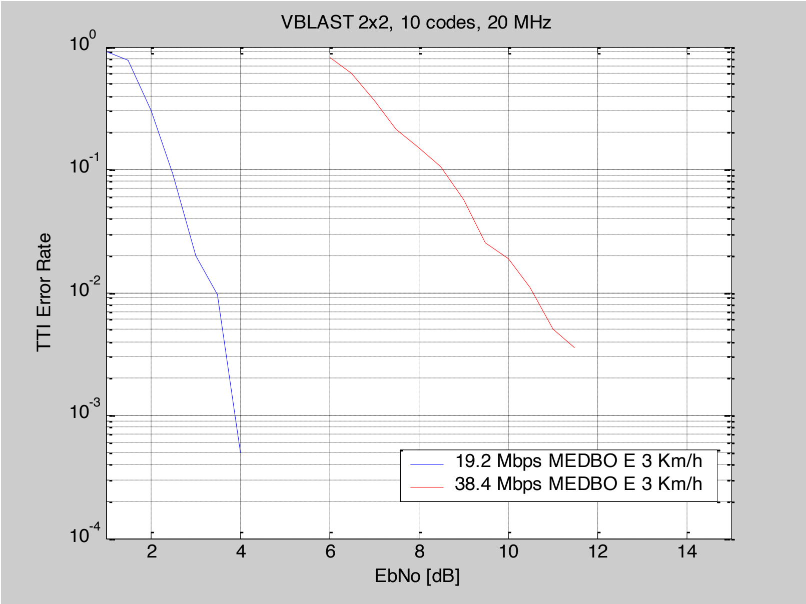


Figure 17. TTI Error Rate versus EbNo for V-BLAST 2x2 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN E channel at 3Km/h.

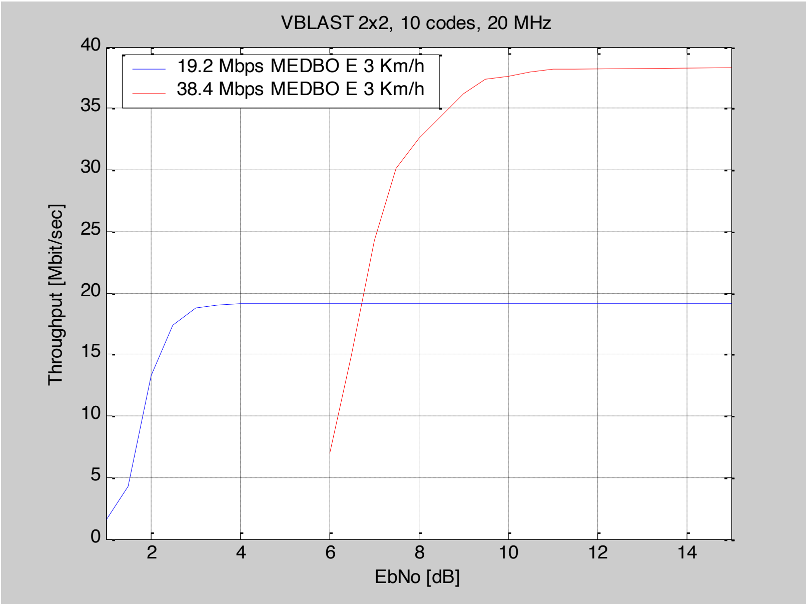


Figure 18. Throughput versus EbNo for V-BLAST 2x2 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN E channel at 3Km/h.

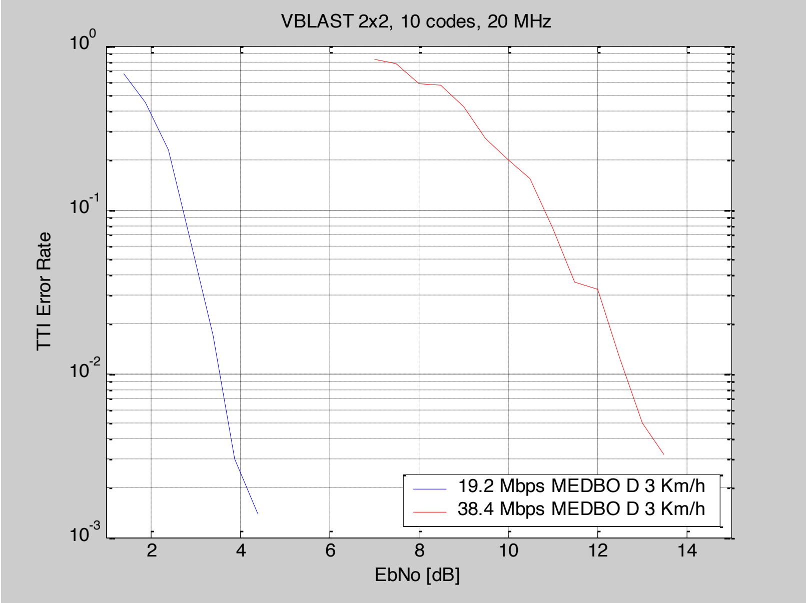


Figure 19. TTI Error Rate versus EbNo for V-BLAST 2x2 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN D channel at 3Km/h.

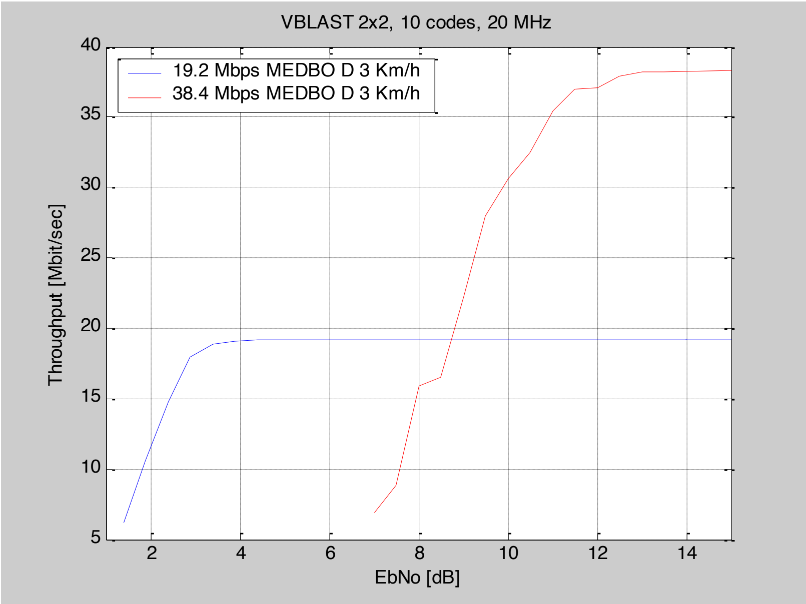


Figure 20. Throughput versus EbNo for V-BLAST 2x2 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN D channel at 3Km/h.

Simulation Results V-BLAST 2x2 at 300km/h

The following figures illustrate results for the V-BLAST scheme with 2 antennas both at the receiver and transmitter side for the channel models of the ETSI BRAN D and E for 300km/h channel. Specifically, two different data rates of 19.2 Mbps and 38.4

Mbps are shown for the V-BLAST 2x2 scheme with 10 codes, coding rate of 0.5 and QPSK or 16QAM modulations. We include both the TTI Error rate versus the EbNo and throughput results.

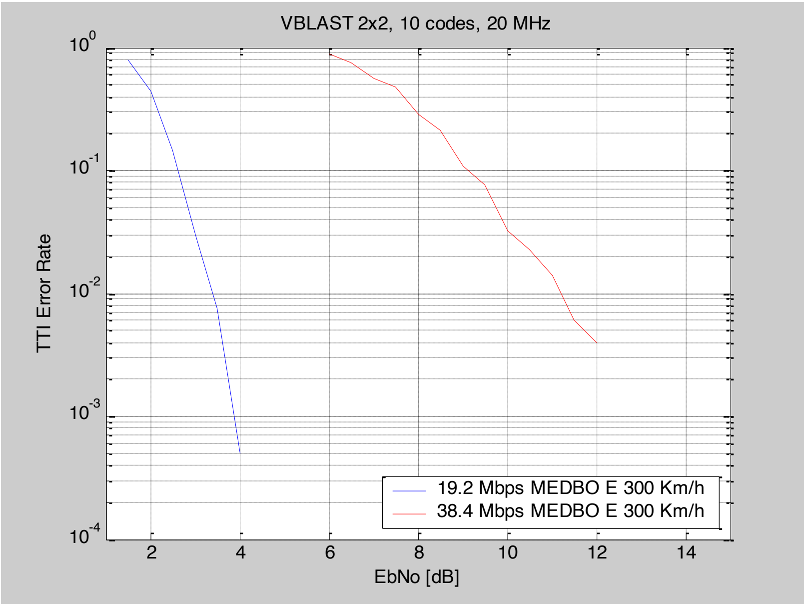


Figure 21. TTI Error Rate versus EbNo for V-BLAST 2x2 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN E channel at 300Km/h.

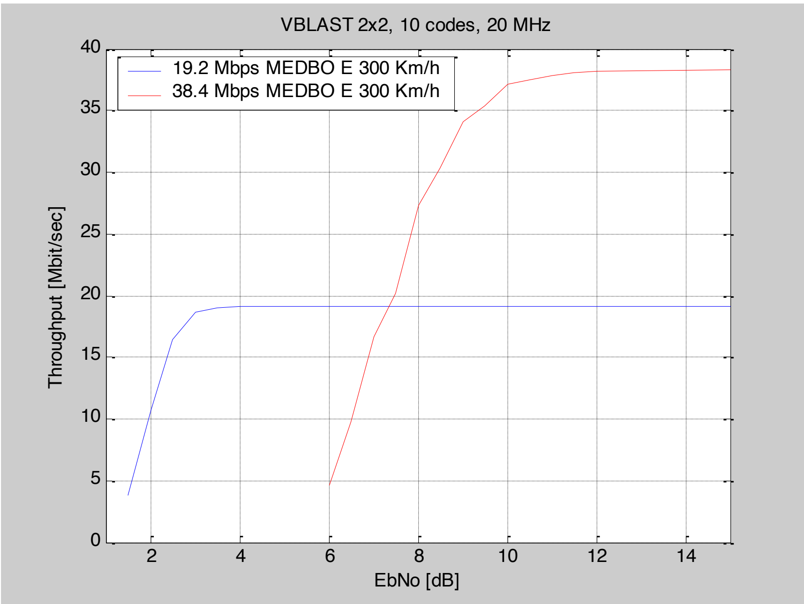


Figure 22. Throughput versus EbNo for V-BLAST 2x2 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN E channel at 300Km/h.

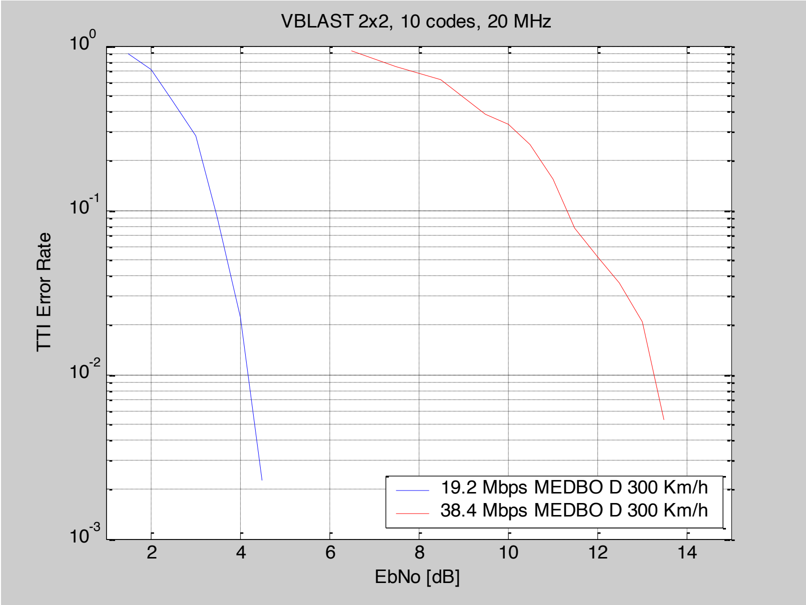


Figure 23. TTI Error Rate versus EbNo for V-BLAST 2x2 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN D channel at 300Km/h.

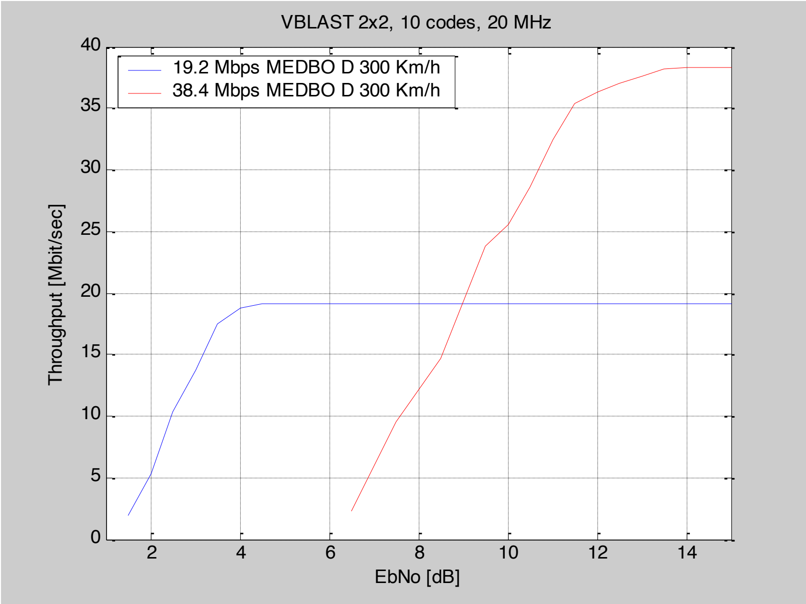


Figure 24. Throughput versus EbNo for V-BLAST 2x2 with 10 codes, coding rate of 0.5, QPSK and 16QAM modulations and for ETSI BRAN D channel at 300Km/h.

2.3 Conclusions

Before evaluating the results, the different scenarios should be taken into account. Model A corresponds to a typical office environment whereas models C and E correspond to typical large open space indoor and outdoor environments with large delay spread. On the other hand, model D corresponds LOS conditions in a large open space indoor or an outdoor environment.

For the Alamouti scheme, the following remarks can be drawn:

- The performance achieved for the ETSI BRAN C and E channels at 3km/h are very similar. This may be due to the fact that both channels show similar delay spreads.

- At 3km/h, the ETSI BRAN A channel performs similarly to the ETSI BRAN C (or E) channel (only 0.5dB more are required by the C channel).

- At 3km/h ETSI BRAN D channel shows the best performance since it requires 2dB less than compared to the ETSI BRAN A channel.

- The results at 300km/h do not change significantly both for the ETSI BRAN D and ETSI BRAN E channels with respect to the results obtained at 3km/h. This may be due to the fact that the proposed scheme assumes perfect channel knowledge at the receiver.

For the V-BLAST scheme, different conclusions arise:

- ETSI BRAN C and ETSI BRAN E channels also perform similarly, but the results for the ETSI BRAN A channel are much worse. At 19.2Mbps, ETSI BRAN A channel needs 7dB of EbNo to achieve the maximum throughput whereas only 3dB are needed for the ETSI BRAN C and ETSI BRAN E channels. The configuration at 38.4Mbps for the ETSI BRAN A channel is not included because it does not perform properly. For the V-BLAST system, the LOS scenario of the ETSI BRAN D channel does not improve performance. This behaviour may be due to the fact that, as it is well known, the V-BLAST system performs very poorly in slow fading channels. Although the UE is moving at the same speed of 3km/h in all the cases, the channels with a larger delay spread provide a larger time diversity that helps the receiver with perfect channel knowledge to decode the symbols.

- Similarly to the Alamouti scheme, results at 300km/h and at 3km/h for V_BLAST neither change significantly for the ETSI BRAN D and E channels. This result is rather surprising because one might expect some improvement at 300km/h due to an increase in the variability of the channel fading. Nevertheless, it seems that the time diversity provided by the delay spread of the channel already copes with the problem of the V-BLAST systems with slow fading channels.

It is also important to remark that the presented simulations assume perfect channel knowledge at the receiver but a practical implementation of the proposed receiver would require an estimation of the channel impulse response. It seems reasonable to expect a higher difference in performance between channels with different delay spreads.

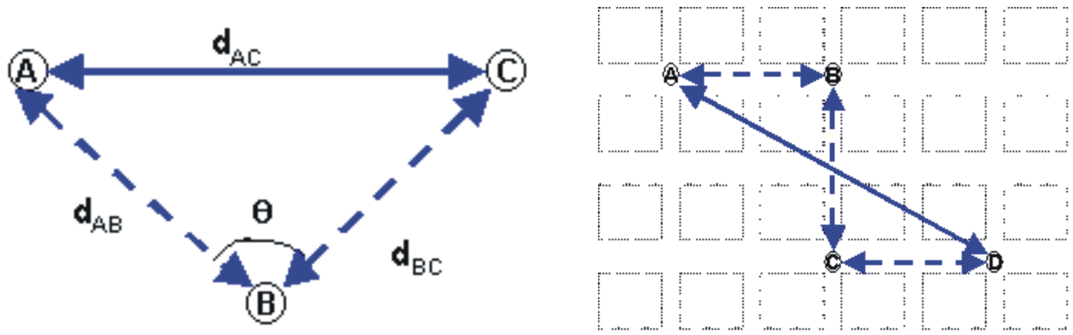
3 COMPARISON WITH MULTIHOP CONCEPT

3.1 Why Multihop?

Consider the situation in Figure 25(a). Assume the path loss exponent is 2 and that a terminal will be able to receive a signal if the received power is at least *P*. Denote the minimum total power required to send a signal from terminal *A* to terminal *C* in the case of direct connection as P_{direct} and the one that it is required by using terminal *B* as a relay as P_{relay}. Then, neglecting the processing power required at terminal *B* for receiving and storing terminal *A*'s signal, we have

$$P_{direct} = P(d_{AB}^2 + d_{BC}^2 - 2d_{AB}d_{BC}\cos\theta)$$

$$P_{relay} = P(d_{AB}^2 + d_{BC}^2)$$



a) Example of relaying b) Street Microcell

Figure 25: A simple relaying model and its extension in a street microcell.

That is, when θ is an obtuse angle, P_{relay} will be less than P_{direct}. This shows that we can transmit the data by breaking down the long path into two smaller hops. The result can be extended simply to the case of using more than one relay and path loss exponents different from 2

In Figure 25(b), the simple relaying scheme described above is extended for a street micro-cell, where the rectangular boxes denote buildings. In a street micro-cell, if the receiver turns around a corner it will experience a dramatic decrease of signal strength by around 20dB [2]. By using a multiple line of sight hop connections like the one depicted in the figure by the dotted path, the huge corner effect could be avoided. This reduction in the total transmitted power will result in an overall interference reduction.

Third generation cellular systems, such as UMTS, are based on CDMA technology. As these systems are inherently interference limited, a reduction in total transmit power will lead to reduced interference thereby improving the system performance, in terms of coverage and capacity.

3.2 ODMA

Opportunity Driven Multiple Access (ODMA) is a cellular multi-hop technique that was proposed as an enhancement of UMTS-TDD mode and was standardized by 3GPP [3][4]. Although the standardisation process has been halted by 3GPP, ODMA is still considered as a potential candidate for future UMTS enhancements [5].

In ordinary TDD mode, terminals near the base station will be able to get high data rate services, while those far away from the base station will have to settle for low data rate services, due to power limitations. The main idea behind ODMA is to increase the range of high data rate services and extend the coverage of the cell, by using relaying, as shown in Figure 26. With ODMA, terminals far away from the base station will be able to access high data rate services because they are able to relay their data via other terminals. As shown in the figure, the dead spots between cell boundaries can also resurrect due to the relaying feature of ODMA.

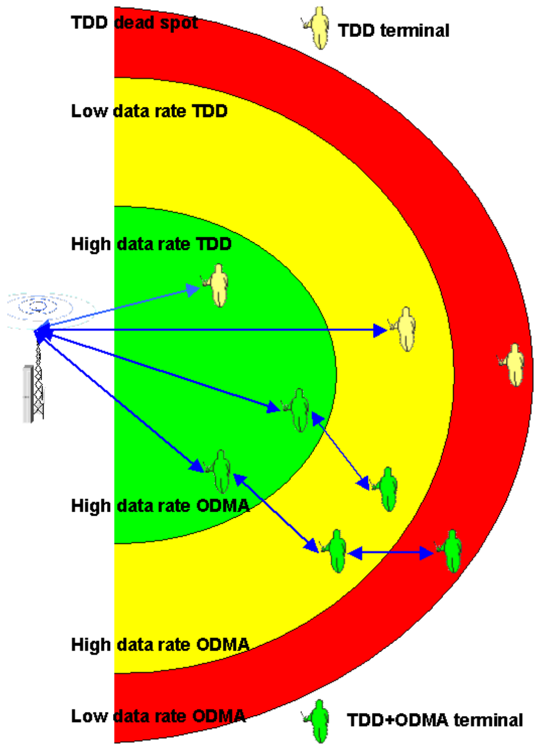


Figure 26: ODMA extension for UMTS-TDD

As mentioned in the previous section, the main aim of relaying is to break the communication path into several shorter links in order to reduce the required total transmission power. As the terminals are moving around the cell(s), a highly dynamic routing algorithm has to be used to find the most optimal hop sequence. The routing algorithm to be used in ODMA is not fully specified in the specification ([3]), but some hints are given on how a terminal could find information about its neighbours.

In normal TDD, the time slots within a frame are allocated (possibly asymmetrically) for uplink and downlink transmission. In ODMA, some time slots will be allocated for relaying purposes. An example of time slot allocation is shown in Figure 27, where 2 slots out of the 15 within a frame are used for relaying purposes. The channels (both control and data) that will be used for relaying will then be using the timeslots allocated for relaying.

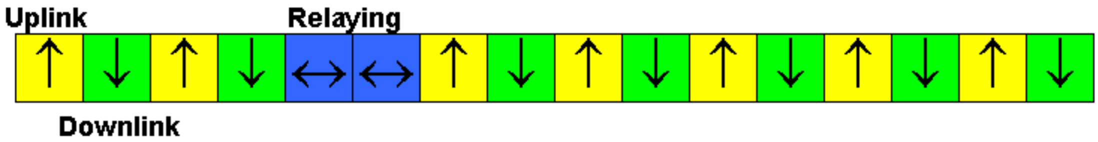


Figure 27: Example of slot allocation for ODMA in UMTS-TDD.

Probing is used to build a list of neighbours, which contains a predefined minimum number of neighbours [3][4]. A terminal will send bursts of data through an ORACH (ODMA Random Access Channel). These bursts contain information on how much it will cost (in terms of power) to send data to the base station from that terminal. The terminal will also listen to similar bursts from other terminals and will register a list of potential relay terminals as neighbours. As the probing activity consumes terminal power by itself, three levels of probing are defined which are chosen based on the number of neighbours to get into the list, the speed and current battery levels. The three probing states are [3]:

1) **Full:** The terminal is idle and is constantly monitoring and transmitting probing bursts in the ORACH.
2) **Duty Maintained:** The terminal will be monitoring and transmitting probing bursts once in a while, based on some scheduling policy, to keep up with the varying network topology. For example, 10% of the time (that is assigned for ORACH), the terminal sends its cost on the ORACH and listen on the ORACH for another 10% of the time, and then use the rest 80% of the time for data transmission and reception.
3) **Relay Prohibited:** In this mode, the terminal ceases to use ODMA and falls back to the normal, direct terminal-base station connection mode of UMTS TDD.

Once a neighbour list is compiled, routing can be done either in a centralised or distributed way. For example, a very simplified version of the Bellman-Ford routing algorithm [6] could be used. As the network topology and link characteristics of the terminals are dynamically changing, the neighbour list of a terminal will be updated in a dynamic way. This leads to the possibility that packets may pass through different routes during the lifetime of a given connection.

Each packet that is sent will have an origin and sink address, as well as the current sender and the next receiver addresses [4]. This double addressing is similar to the one used in IP+Ethernet addressing for internet packets [7], where a node knows that the packet is destined for it if the two addresses (destination and next receiver) are the same to its address. Otherwise, the packets will be forwarded to another terminal that will take them closer to the destination terminal, based on the routing scheme employed. Some timing information, such as TTL (time to live) could be appended also on the packet header. Such information could be useful for scheduling purposes [8].

Small amount of data can be sent via the ORACH using bursts with addresses. Large amount of data cannot be sent over the ORACH due to the contention-based access mechanism employed by random access channels. Instead, dedicated channel (DCHs) will be used. Each ORACH has an associated set of DCHs. Addressed data probe will be sent on the ORACH to establish the connection and the data transmission will continue on the DCH associated with the ORACH [4].

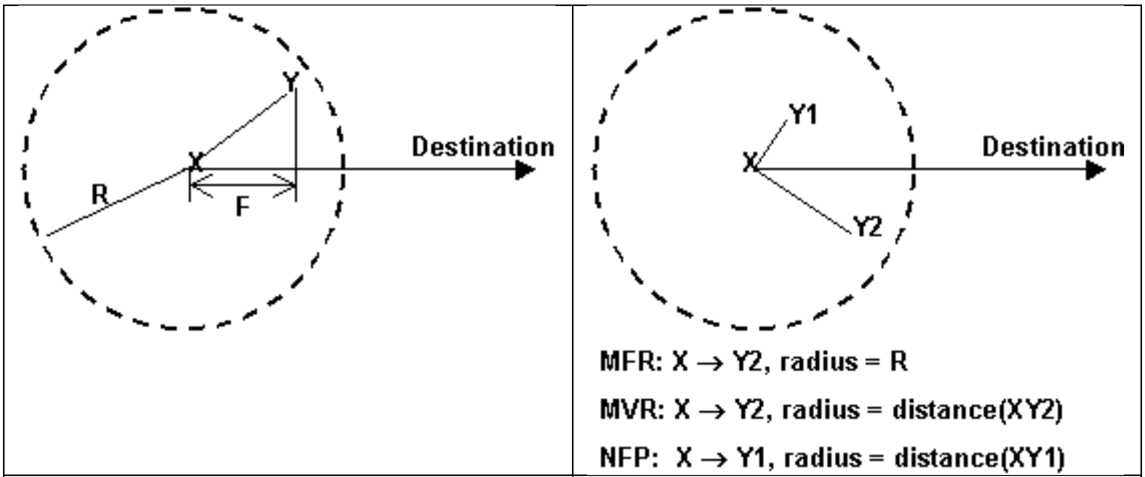
3.3 Review Of Related Work

There is a large body of research related to the investigation of multihop cellular networks. In this section, a brief description of some of the interesting works will be given.

The earliest investigations on multi-hop systems were done on TDMA packet radio systems [9][10]. In [9], analytical investigation of a slotted ALOHA system is performed. The terminals in the system are assumed to be identical and to have packets to transmit all the time. Terminals are distributed in accordance with a two-dimensional Poisson distribution. The routing strategy used was Most Forward within Radius (MFR). In MFR, a transmitter sends its data to the terminal within its transmission radius that will result in the most forward progression of the packet towards the destination terminal (see Figure 28). If no terminal is found within the transmission radius, the concerned slot will be skipped. The performance of the system is measured based on the expected forward progress of a packet per slot. It is shown that the optimal configuration is where each terminal transmits once in every ninth time slot.

In [10], a similar system was compared with other routing algorithms. In addition to MFR, Nearest with Forward Progress (NFP) and Most Forward with Various Radius (MVR) routing schemes are also investigated (see Figure 28). MVR is similar to MFR, except that the transmission range is adjusted to be just equal to the one required between the transmitter and receiver. In NFP, the transmission will be done to the nearest terminal that will result in a forward progress, and the transmission power is adjusted accordingly. The NFP scheme is shown to be the best of the three methods in terms of expected forward progress, while MFR is the worst.

In [11], a CDMA packet radio system is considered. Only path loss is considered in the propagation modelling. Assuming a relay terminal node can be found exactly where needed, it is found that the optimum strategy is to address the packet such that there are $1.3\sqrt{K}$ terminals (where K is proportional to the processing gain used by the CDMA system) between the transmitter and receiver.



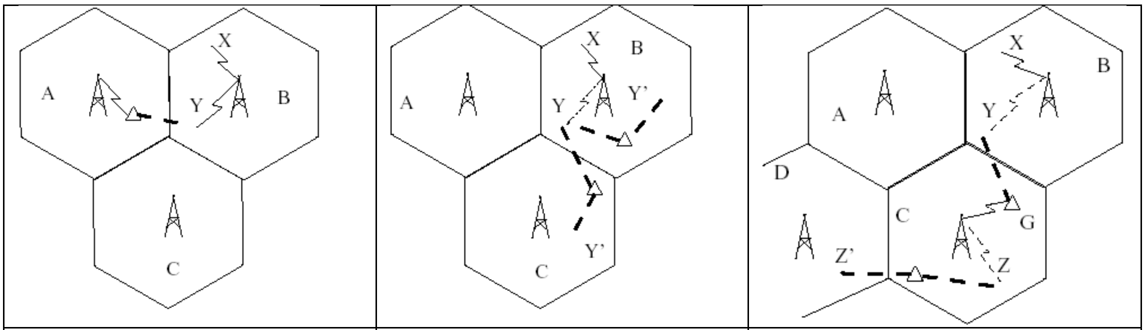
a) Forward Progress | b) Transmission strategies

Figure 28: Transmission strategies for multihop packet radio networks [10].

In [9], [10] and [11], the performance measure considered (expected forward progress) is too simplistic to be useful for practical purposes. However, the results show multihopping as a feasible way of transmission, if the system parameters are chosen properly, and pave the way for future researches in multihop networks.

A method of integrating cellular infrastructure with Ad-hoc relaying technologies, known as ICAR (Integrated Cellular and Ad-hoc Relay), is described in [12]. The main aim of ICAR is to achieve dynamic load balancing among different cells in a cost-effective way (see Figure 29). A number of ad-hoc relay stations (with some limited mobility) were placed at strategic locations (a novel approach on finding the strategic locations are described in [12]), which are then used to relay packets from the terminals to the base stations. The relays are mainly used to divert traffic from congested cells to non-congested cells, thus leading to enhanced coverage and reliability of the system. Using simulations, it is shown that the number of new connections that can be accepted increases almost linearly with the number of relays.

In [13], a performance comparison of IEEE 802.11 ([14]) ad hoc (i.e. multi-hop) and infrastructure (similar to cellular) modes is given. Simulation results show that while the ad-hoc mode performs better in terms of throughput, delay, and power, it suffers from unfairness and poor network performance in the event of mobility. The authors propose a hybrid model in which the terminals operate in ad-hoc mode by default, but switch to the cellular mode if throughput falls below from the one that is expected from cellular mode. The decision to do so is made by the base station and communicated to the terminals via a control channel, and it is shown that the hybrid model combines the advantages of the two modes (see Figure 30).



a) Terminal Y to base station A	b) Terminal Y to terminal Y'	c) Cascaded relaying

Figure 29: Examples of relaying to free up channels in ICAR [12].

The effect of using fixed relays in a cellular system is investigated in [15]. A base station is located at the centre of a cell, surrounded by a ring of six repeaters. The relays form a hexagon and they are located somewhere in-between the centre and the cell boundary. CDMA is used as the access technique and terminals and relays are synchronised. Repeaters receive data in one time slot and retransmit the data in a different time slot (using the same frequency), and repeaters are assumed to have several channels available to them. Closed form formulas were obtained for the interference and throughput of the system. Numerical results show that the relying highly improves the throughput of the system, when the system power consumption is kept the same as in the non-relayed case. The authors have extended their work in [16] to cover relays that are randomly distributed throughout the cell and a closed form formula for the probability density function of the interference at each receiver is derived. In [17] and [18], methods of improving the performance of wireless networks (such as diversity, smart antennas and multi-user detection) are discussed from the point of view of multihop cellular networks.

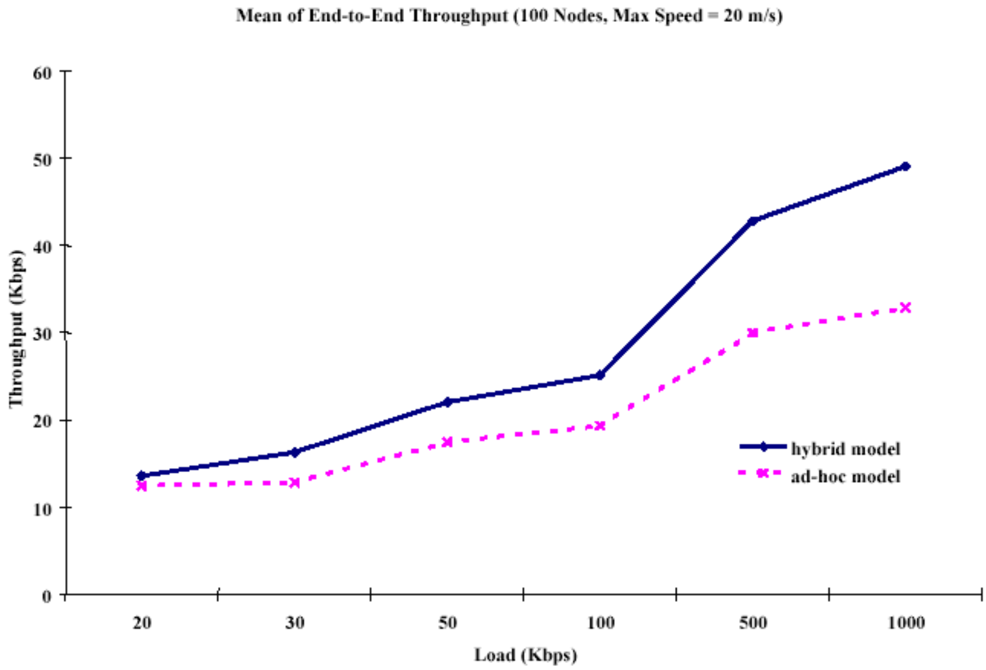


Figure 30: Performance improvement of hybrid model [13].

In [19], [20], [21], simple multi-hop wireless systems are investigated. The systems use a combination of fixed and/or mobile relays. A very simple routing mechanism, where a transmitter uses a direct connection if it is able to do so within its power limit, is employed. Otherwise, the terminal can use a maximum of one other relay to transmit its data. Using simulations, it is shown that for terminals located near the cell edges, relaying is very effective in reducing the required transmission power, thereby reducing the overall interference and increasing area coverage of the system while preserving the end-to-end throughput of the system (see Figure 31).

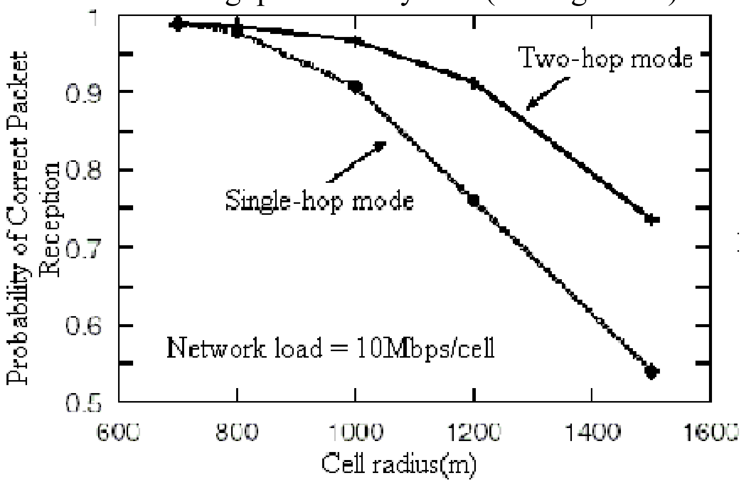


Figure 31: Coverage improvement due to relaying [20].

In [22], the performance of a system employing ODMA is investigated. Simulations were performed for both single and multiple cell scenarios. The routing used is a simplified version of the one specified in [3] and [4]. The results show that ODMA can bring up to 10dB reduction in interference (both in Uplink and Downlink) in the multiple cell environments, as compared with a non-relaying UMTS TDD system.

A similar investigation on ODMA is undergone in [23] for a single cell scenario. It is shown that ODMA extends the coverage of a cell, but only after the cell size is large enough to prevent a comparable single hop system from achieving its maximum capacity (see Figure 32). ODMA is also shown to be more fair than a single hop cellular system by making the outage probability almost distance independent (in the non-ODMA case, the users farther away from the base station have greater outage probability than the ones that are closer.)

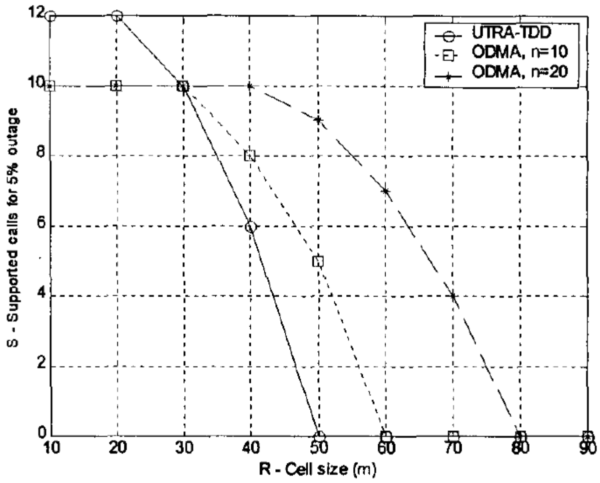


Figure 32: Supported number of users per time slot against the coverage of the cell, for less than 5% outage probability. "n" is the number of idle users available for routing [23].

In [28], a virtual currency mechanism, known as nuglets, for rewarding terminals that are relaying data is described. As shown in Figure 33, there are two ways of using this mechanism. In the first method (cases a and b in the figure), the sender loads the packets that it is sending with a certain amount of nuglets. Each relaying node will acquire some nuglets from the packet that covers its forwarding cost (Figure 33(a)). If the nuglets within the packet are less than the required by a forwarding node, they are dropped (Figure 33(b)). In the second method (cases c, d, and e in the figure), the packets will not be carrying nuglets. Instead, each intermediary node buys a packet and sells it to the next one for more nuglets (Figure 33(c)). Nodes can negotiate the price of packets with other nodes as shown in Figure 33(d) and (e). By using the nuglets mechanism, terminals will be rewarded for the battery power they spend for relaying purposes, and thus the cooperation among the terminals within a cell is enhanced.

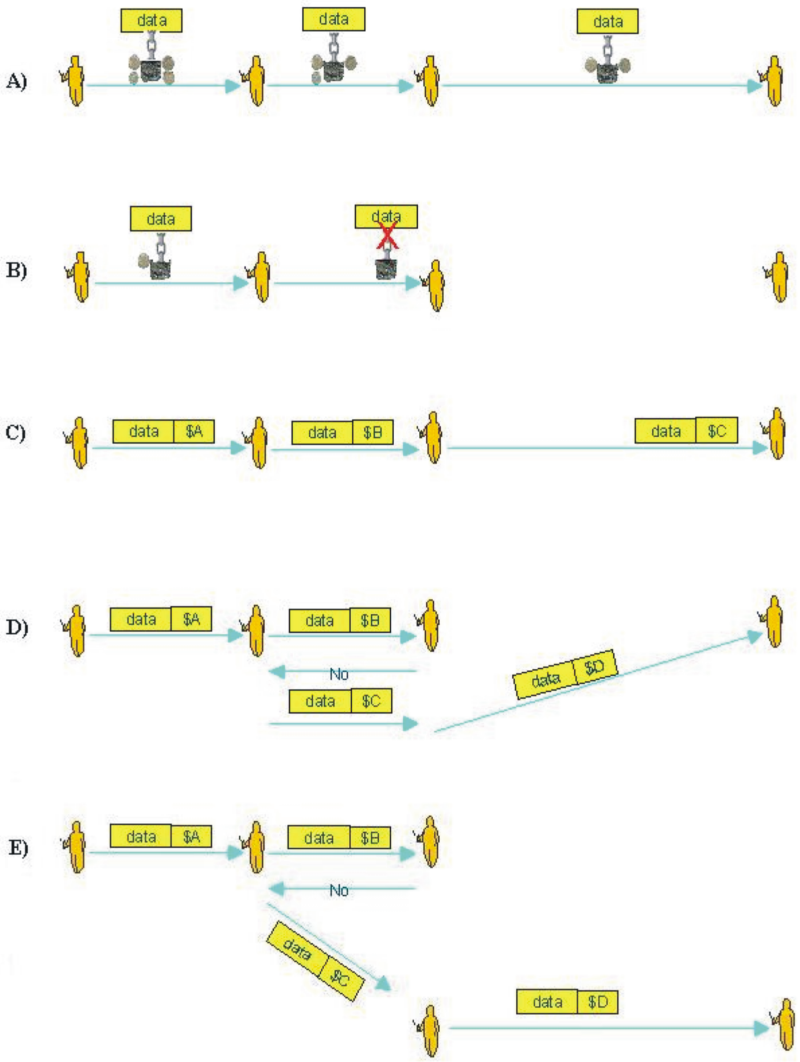


Figure 33: Nuglets at work. a) There is enough nuglets to reach destination b) Not enough nuglets, so packet is not relayed c) The second node buys the packet for A nuglets and sells it for B nuglets and so on. D) Third node was not willing to pay B nuglets, so the price was reduced to C nuglets and transmission resumed. E) Since the third node refused the offer, another node is selected as a relayer.

3.4 Challenges and Open Issues

Though some of the results mentioned in the previous section indicate multihopping can lead to performance enhancement of wireless networks, a lot of issues have to be taken care of in order to make multihop cellular networks a reality. Following is a brief description of some of them:

1. **Mobile-to-Mobile Propagation Model:** Most propagation models that are currently in use assume that base station antennas are higher than 30m and terminal antennas are operating at around head height (2m) [24]. In the relaying case, both transmit and receive antennas are expected to be low and

relaying terminals are very likely to be in very unfavourable conditions such as in users pockets and bags [25]. Thus, multihop cellular investigations should take these effects into account.

2. **Routing and associated overhead:** The routing strategy used for multihop networks should be robust in order to cope with moving mobile terminals, and to make the connection establishment and packet round trip delays acceptable. A combination of minimum energy and location aware routing schemes, where each terminal is aware of its and its immediate neighbours' locations, seems to be the most promising approach [26] [27]. However, careful study of these schemes should be done as these may lead to high singling overhead and hence overall performance degradation.

3. **Incentive for relaying**: A terminal's battery may be drained without the user using it for his/her own connection simply because it was used to relay other users data. In order to make this acceptable, users should be rewarded for relaying, for instance by giving them free connection time based on the amount of data they have relayed. The nuglets mechanism described in the previous section seems to be promising though its performance is yet to be thoroughly investigated.

4. **Power control:** In interference limited cellular systems such as CDMA, power control is used to control the transmission power of the terminals to prevent the so called near-far effect, which is caused by terminals near the base station overwhelming those that are far away. In centralized system, well-known power control mechanisms exist that try to increase or decrease the transmission power depending on how much interference the mobile is suffering from [29]. The power control in multihop systems is much more complicated. This is mainly because the base station will not be able to control the power centrally given the fact that there are peer-to-peer and relayed communication going on within the cell, i.e. we have to deal with "multiple near far effects" between several receiver-transmitter pairs instead of just one "mobile-base station" near far effect. Distributed power control, where terminals use control signals to communicate the amount interference they can live with, and determine their transmission power based on the control signals they receive from other terminals, seems to be a promising solution. One such power control mechanism for multihop systems is described in [30].

5. **Access Mechanism:** Multiple access (CDMA, TDMA, FDMA, OFDMA) and multiplexing (FDD, TDD) schemes have to be investigated in order to find out if they are suitable for multihop cellular networks. The access and multiplexing scheme to be used can have an impact on the terminal complexity and cost. In UMTS, for example, relaying is more suitable for TDD mode. If FDD is used, then the transmitting unit of the terminals has to be modified (i.e. more expensive terminals) so that they could be able to transmit at downlink frequency (when forwarding downlink data), and receive at uplink frequency (when receiving uplink data that is going to be forwarded). There is also a possibility of using dual mode terminals, where TDD is used

for direct terminal to terminal communication and FDD being used for the mobile to base station communication, as described in [4].

3.5 Summary

Cellular systems with the possibility of peer to peer communication or communication that is relayed through other fixed or mobile terminals are known as Multihop Cellular Networks, as compared with Centralized Cellular Networks where every communication has to pass through a central base station.

In this sub-task, an overview of multihop cellular networks was presented. By reducing the total transmitted power and thereby reducing the total interference in cellular systems, multihop extensions are expected to play an important role in future, high data rate wireless networks. Several issues have to be resolved before multihop cellular networks can be a reality and the most pressing ones were discussed including hints towards promising solutions.

4 REFERENCES

[1] W. Mohr, R. Lüder, and K. H. Möhrmann, “Data Rates Estimates and Range Calculations for New Elements of Systems Beyond IMT-2000”, WWRF Research Forum, 2002.

[2] J. B. Andersen, T. S. Rappaport, and S.Yoshida, “Propagation Measurements and Models for Wireless Communication Channels”, IEEE Communications, vol. 33, no. 1, pp. 42–49, January 1995.

[3] 3GPP, “Opportunity Driven Multiple Access”, 3G TR 25.924 V1.0.0, December 1999.

[4] ETSI, “UMTS Terrestrial Radio Access (UTRA) Concept Evaluation”, TR 101 146 V3.0.0, December 1997.

[5] T. Rouse, I. Band, and S. McLaughlin, “Capacity and Power Investigation of Opportunity Driven Multiple Access (ODMA) Networks in TDD-CDMA Based Systems”, IEEE International Conference on Communications, vol. 5, pp. 3202–3206, 2002.

[6] L. R. Ford and D. R. Fulkerson, “Flows in Networks”, Princeton University Press, 1962.

[7] W. R. Stevens, “ TCP/IP Illustrated, Volume 1”, Addison-Wesley, 1994.

[8] G. Mildh, “Performance Evaluation of Opportunity Driven Multiple Access in UMTS/TDD”, M.S. thesis, Royal Institute of Technology (KTH), Sweden, 2000.

[9] H. Takagi and L. Kleinrock, “Optimal transmission ranges for randomly distributed packet radio terminals”, IEEE Transactions on Communications, vol. COM-32, no. 3, pp. 246–257, March 1984.

[10] T. Hou and V. Li, “Transmission range control in multihop packet radio networks”, IEEE Transactions on Communications, vol. COM-34, no. 1, pp. 38–44, January 1986.

[11] E. S. Sousa and J. Silvester, “Optimum transmission ranges in a direct-sequence spread-spectrum multihop packet radio network”, IEEE Journal On Selected Areas In Communications, vol. 8, no. 5, pp. 762–770, June 1990.

[12] C. Qiao and H. Wu, “iCAR: an integrated cellular and ad-hoc relay system”, Ninth International Conference on Computer Communications and Networks, pp. 154–161, 2000.

[13] H. Hsieh and R. Sivakumar, “Performance comparison of cellular and multi-hop wireless networks: a quantitative study”, Proceedings of the 2001 ACM SIGMETRICS international conference on Measurement and Modeling of computer systems, pp. 113–122, 2001.

[14] ISO/IEC, “IEEE 802.11 Local and Metropolitan Area Networks: Wireless LAN Medium Access Control (MAC) and Physical Specifications”, 8802-11:1999, http://grouper.ieee.org/groups/802/11/.

[15] A. N. Zadeh and B. Jabbari, “Throughput of a Multihop Packet CDMA Network with Power Control”, Vehicular Technology Conference, vol. 1, pp. 31–35, May 2000.

[16] A. N. Zadeh and B. Jabbari, “On the Capacity Modeling of Multi-hop Cellular Packet CDMA Networks”, IEEE MILCOM, vol. 1, pp. 600–604, October 2001.

[17] A. N. Zadeh and B. Jabbari, "A High Capacity Multi-hop Packet CDMA Wireless Network", First ACM Wireless Internet Workshop, pp. 83-88, July 2001.

[18] A. N. Zadeh, B. Jabbari, R. Pickholtz, and B. Vojcic, "Self-organizing Packet Radio Ad hoc Networks with Overlay (Soprano)", IEEE Communications Magazine, vol. 40, no. 6, pp. 149–157, June 2002.

[19] Y. Yamao, T. Otsu, A. Fujiwara, H. Murata, and S. Yoshida, "Multi-hop Radio Access Cellular Concept for Fourth-Generation Mobile Communications System", 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, vol. 1, pp. 59–63, 2002.

[20] A. Fujiwara, S. Takeda, H. Yoshino, and T. Otsu, "Area Coverage and Capacity Enhancement by Multihop Connection of CDMA Cellular Network", 56th IEEE Vehicular Technology Conference, vol. 4, pp. 2371–2374, 2002.

[21] S. Takeda, A. Fujiwara, H. Yoshino, and T. Otsu, "Performance Evaluation of a Time Division Multi-hop Relay Scheme in CDMA Cellular Networks", 57th Vehicular Technology Conference, 2003.

[22] O. B. Holm, T. Friiso, and T. Haslestad, "Improving UTRA Capacity with ODMA", IST Mobile Communications Summit, 2002.

[23] T. Rouse, S. McLaughlin, and H. Haas, "Coverage-Capacity Analysis of Opportunity Driven Multiple Access (ODMA) in UTRA TDD", 2nd International Conference on 3G Mobile Communication Technologies, no. 477, pp. 252–256, 2001.

[24] T. S. Rappaport, "Wireless Communications, Principles & Practice", Prentice Hall, 1996.

[25] T. J. Harrold, A. R. Nix, and M. A. Beach, "Propagation Studies for Mobile-to-Mobile Communications", 54th IEEE Vehicular Technology Conference, vol. 3, pp. 1251–1255, 2001.

[26] R. Jain, A. Puri, and R. Sengupta, "Geographical Routing Using Partial Information for Wireless Ad hoc Networks", Tech. Rep. UCB/ERL M99/69, University of California, Berkeley, December 1999.

[27] V. Rodoplu and T. H. Meng, "Minimum Energy Mobile Wireless Networks", IEEE Selected Areas in Communications, vol. 17, no. 8, pp. 1333–1344, August 1999.

[28] L. Buttysan and J. P. Hubaux, "Nuglets: a Virtual Currency to Stimulate Cooperation in Self-Organized Mobile Ad Hoc Networks", Tech. Rep. DSC/2001/001, Swiss Federal Institute of Technology-Lausanne, January 2001.

[29] J. Zanders, "Radio Resource Management For Wireless Networks", Artech House, 2001.

[30] F. Fitzek, P. Seeling and M. Reisslein, "Link Level Design Issues for IP based Multi-Hop Communication Systems", WWRF Research Forum, 2002.

[31] IST-2000-30148 I-METRA, Deliverable 6.1, "Implications in Re-configurable Systems beyond 3G. Part 1", available at www.ist-imetra.org

[32] IST-2000-30148 I-METRA, Deliverable 3.2 "Implementation of Relevant Algorithms ", available at www.ist-imetra.org

[33] IST-2000-30148 I-METRA, Deliverable 4 "Performance Evaluation", available at www.ist-imetra.org