Handover Optimization in WiMAX Vehicular Communications

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***Abstract*—The WiMAX communications for vehicular is a topic of significant interest for research and industry communities, on both V2V (vehicle–to-vehicle) and V2I (vehicle-to-infrastructure) situations. This paper presents results of an experimental study, simulation based, directed to determine multi-dimensional regions where different lower layers parameters have influence on the overall handover performance in mobility scenarios, related to WiMAX V2I communications. The simulations results are consolidated in multi-dimensional graphs, named decision spaces. Based on them, optimal parameter sets can be provided by the network operator to vehicular mobile station, to guide its adaptation of the major WiMAX parameters to its speed and network topology and to help the handover decision.**

Keywords-WIMAX vehicular communications; antenna gain; scanning; handover; cross layer interaction

I. INTRODUCTION

The WiMAX communications for vehicular use has gained a continuous attention from research community, on both V2V (vehicle-to-vehicle) and V2I (vehicle-to-infrastructure) situations. This paper presents a detailed experimental study related to WiMAX V2I communications.

This work aimed to determine multi-dimensional regions where different lower layers parameters have influence on the overall handover performance in mobility scenarios related to WiMAX V2I communications.

Given the high number of WiMAX physical and MAC layer parameters influencing in an inter-dependent mode the overall performance in mobility scenarios, experimental simulation studies of complex scenarios are very helpful to determine the combined effect on such parameters. In this work the simulations results are consolidated in multidimensional graphs, named decision spaces. These decision spaces present in aggregated form the performance obtained in a WiMAX V2I mobility scenario, related on a specific trajectory. The results can be used as a method of optimizing the vehicular communications by guiding the handover (HO) decision. Based on decision spaces, optimal parameter sets can be provided by the network operator to vehicular mobile station, in order to adapt the major WiMAX parameters to its speed and network topology.

The effect at different PHY parameters adjustments on the throughput values has been evaluated, to determine some decision regions space usable to optimize working ranges of parameters in case those policies are applied to govern the handover. That is why we called the aggregated simulation results diagrams as "decision spaces".

The optimal parameter sets obtained from decision spaces can be provided by a network operator to mobile station (MS), helping it to adapt dynamically its behavior and to obtain the maximum throughput possible from network at different speed, antenna gain, maximum transmission (Tx power), and scanning values.

The paper is organized as follows: the Section II presents some related work. The Section III defines the simulation context. The Section IV describes the simulation results. Conclusion, open issues and future work are shortly outlined in the Section V.

II. RELATED WORK

In [1], the authors propose study the feasibility of using WiMAX for V2I communication on a static setting in urban environment and perform a comparison with use of WiFi.

Pegasus, a system providing wireless connection roaming at high velocities over multiple interfaces uses network information for user locations and used paths for effective and balanced utilization of the available bandwidth [2].

The reference [3] evaluates an architecture based on IEEE 802.21 framework, integrating both mobility and Quality of Service (QoS) mechanisms, through an advanced mobility scenario using a real WiMAX testbed.

In [4], mobile WiMAX trials are analyzed to investigate the vehicular downlink performance for a number of on-car antenna configurations.

This work presented is a continuation of a set of complex studies on WiMAX mobility. First results have been shown in a study of HO performance for WiMAX mobility [5], continued with an WiMAX HO conditions evaluation towards enhancement through cross-layer interaction proposed in [6], together with a SIP-based cross-layer optimization for WiMAX Hard HO method, described in [7].

III. SIMULATIONS CONTEXT

There are numerous studies about WiMAX mobility and methods of optimizing the V2I communications. However, an analysis of V2I system behavior on incremental variance of speed, antenna gain, maximum Tx power, and scanning threshold/methods could add new value to existing optimization methods.

All simulations were done in OPNET v.14.5. [8] A typical mobility scenario has been considered (linear trajectory along a road where WiMAX BS stations are located). The BSes use the same set of frequencies and the mobile station (MS) is moving on a linear trajectory along the chain of BSEs. The utility of such a scenario is that it is similar with a road region in which WiMAX station are located along the road and the MS is a vehicle moving on the road.

The parameters taken into considerations (used in pairs in batteries of simulations) have been: (Table 1)

- MS Transmission Power (W)
- MS Antenna Gain (dBi)
- MS Scanning Threshold (dB)
- MS HO Threshold Hysteresis (dB)
- BS Transmission Power (W)
- BS Antenna Gain (dBi)

Table 1 WiMAX Parameters

	WiMAX Parameter	1	2	3	4	5	6	7	8	9	10
A	MS Maximum Tx Power (W)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
B	MS Antenna Gain (dBi)	-1	0	2	4	6	8	10	12	14	16
C	MS Scanning Threshold (dB)	3	6	9	12	15	18	21	24	27	54
D	MS HO Threshold Hysteresis (dB)	0.4	2	4	6	8	10	12	14	16	18
E	BS Maximum Tx Power (W)	0.5	0.8	1	1.3	1.5	1.8	2	2.3	2.5	2.8
F	BS Antenna Gain (dBi)	6	8	8	9	10	12	14	15	16	21

Each set of simulations considered the variance of a pair of parameters, the rest of them remain unchanged. The final value of average application throughput for each simulation is represented as a single point in the related decision space. In that way, each decision space covers 100 instances of a scenario, describing in details the behavior of V2I communication quality under effects of WiMAX parameters pair variance, on that particular trajectory and network topology.

IV. SIMULATION RESULTS

Due paper size limitations, only MS Maximum TX Power-MS Antenna Gain, MS Antenna Gain-MS Scanning Threshold, MS Scanning-Method MS Speed, MS HO Threshold Hysteresis-MS Speed, MS Maximum TX Power-BS Antenna Gain, and MS Maximum TX Power - MS Antenna Gain decision spaces will be presented. Each vertical section on decision space provides an analysis of system behavior under influence of a single parameter variance (depending on the selected axis).

A. Influence of Maximum transmission power and MS antenna gain

This experiment has been simulated while letting the Maximum TX power and antenna gain to pass through all specified values, for a MS speed of 10m/s and respectively 50 m/s. The scanning method had parameters: N=4 P=240 T=10. N=scanning (frames), P=interleaving (frames), T=iterations. The rest of parameters have been constant. Simulations set: A_B_C01 D01 E01 F01 for low speed (s=10m/s).

The diagrams from Fig. 1 and Fig. 2 show MS Maximum TX Power-MS Antenna Gain decision space for MS speed of 10m/s and respectively 50 m/s, giving an overall idea on the relative performance without presenting details on each HO action.

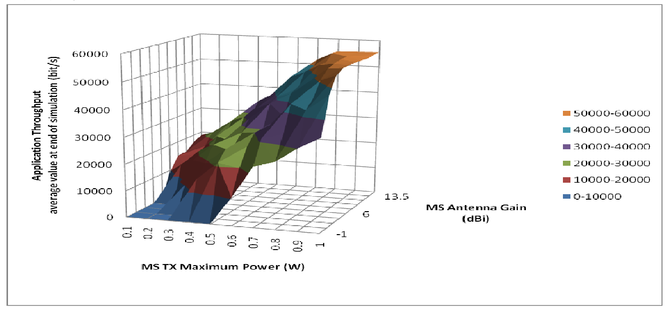

Figure 1. MS Maximum TX Power - MS Antenna Gain -- Decision Space for MS Speed 10m/s

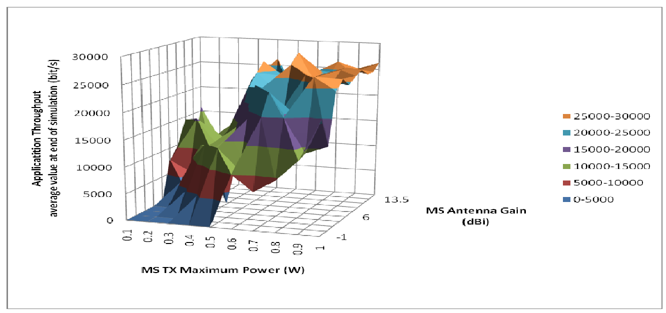

Figure 2. MS TX Maximum Power - MS Antenna Gain -- Decision Space for MS Speed 50m/s

It is seen that speed has a major impact on the throughput. Out of theoretical throughput of 64 kbps (source rate) for high speed s= 50 m/s, the results are significantly worse than for low speed as 10 m/s, for the same range of TX power and antenna gain. While for s= 10 m/s we get for sufficient TX power (> 0.5W) and antenna gain (> 8Db) a throughput closer to 64 kbps, while in the same conditions we get for the s= 50 m/s case, only something close to 30kbps, i.e. half. Therefore, in such cases MS need a higher TX power and higher antenna gain. Also in the case of high speed, the effect of vehicular channel is higher than for low speed (see the non-monotonic behavior of the second diagram).

Fig. 3 shows details of important antenna gain effect in the conditions where only Maximum TX power is varied (vertical section on MS Maximum TX Power-MS Antenna Gain decision space for MS speed 10m/s).

The diagrams show that even if we have an increase of maximum TX power ten times (i.e. from 0.1W to 1W), the overall throughput achievable is modest one (i.e. only 22kbps), if g= 0dB, while for a gain of g= 10dB (right diagram) it is seen that the throughput increases more than 100%. This result clearly shows the benefit of a directional antenna, which may have a high gain versus a conventional omni directional one.

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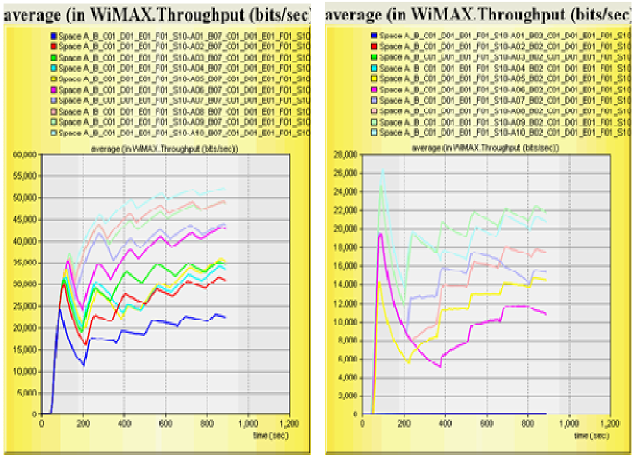

Figure 3. Effect of antenna gain (g= 0DBi – left, and g= 10dBi – right) on throughput in Maximum TX power variation conditions, s = 10m/s.

Fig. 4 shows the same diagrams as in Fig. 5 but for s = 50 m/s (vertical section on MS Maximum TX Power-MS Antenna Gain decision space for MS speed 50m/s).

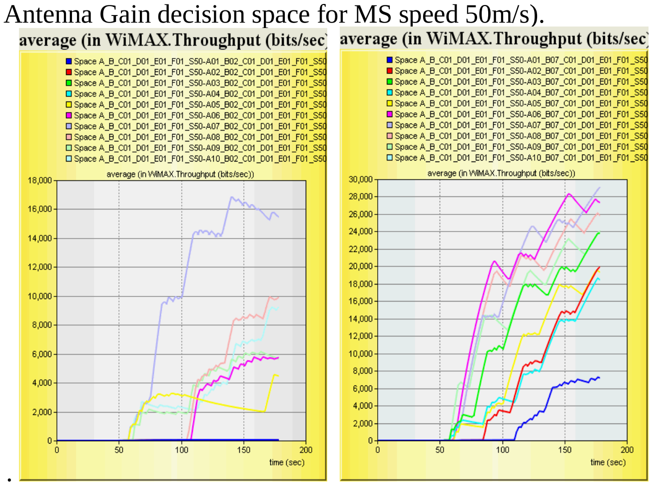

Figure 4. Effect on throughput of Maximum TX power variation conditions, while the antenna gain is fixed (g= 0dBi – left, and g= 10dBi – right); s = 50m/s (180 km/h).

It is seen that high speed would worsen the behavior. For instance, for s = 10 m/s we get a throughput of 55 kbps (out of 64 kbps), in the conditions (P= 1W and g = 10dBi) , while for s = 50 m/s, even the gain and maximum TX power is high, the maximum throughput at the end of simulation is only close to 28 kbps. Still the gain of antenna is important (increase from 16kbps to 28 kbps).

Therefore, even in adverse condition (related to Maximum TX power), the gain of the antenna can significantly improve the performance. The left diagram confirms that, even if MS has high Maximum TX Power, a very low antenna gain prevents the system of getting sufficient performance. The HO gaps have still large values in time (tens of seconds) at P = 1W. On the other side, if MS has a gain of g= 10dBi (right diagram), it is shown that throughput is good in the range P > 0.7W and increasing this power does not bring significant additional increase in throughput. These are the confirmation on detailed experiments of the conclusions drawn for synthesis diagrams.

B. *Influence of MS antenna gain and scanning threshold*

This section studies the scanning process influence on the performance in the given linear configuration and together with other parameters among which we are mainly interested in antenna gain effects.

A short summary of scanning process is given here as reminder. When the fading SNR reaches the scanning threshold, the MS begins with scanning process on the announced DL channels by sending the MOB-SCN-REQ message. The BS allows for scanning by replying with the MOB-SCN-RSP message that contains the parameters for scan duration (N), interleaving interval (P) and the start frame (M). After receiving the MOB-SCN-RSP from the target BS, the SS starts the scanning after M received frames (start frame). The SS changes after M frames to the next channel and stays there for an N frames period (scanning interval/duration) to detect a BS and to assess its SNR.

After a scanning interval, the SS returns to the DL channel of the active BS. This behavior aims to keep the interruption as short as possible since no payload transmissions are possible during the scanning process. If no preferable BS could be detected on the scanned channel, it reinitiates the scanning mode after a P frames period (interleaving interval) to find a new BS. The total number of allowed repetitions of the scanning process is given with the parameter (T).

The diagrams from Fig. 5 and Fig. 6 show the cumulative throughput at the end of simulation time, while the antenna gain and scanning threshold have been varied, again taking two MS speed values of 10 and respectively 50 m/s.

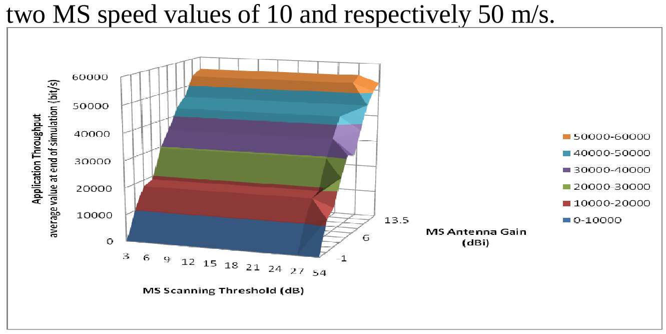

Figure 5. MS Antenna Gain - MS Scanning Threshold -- Decision Space for MS Speed 10m/s

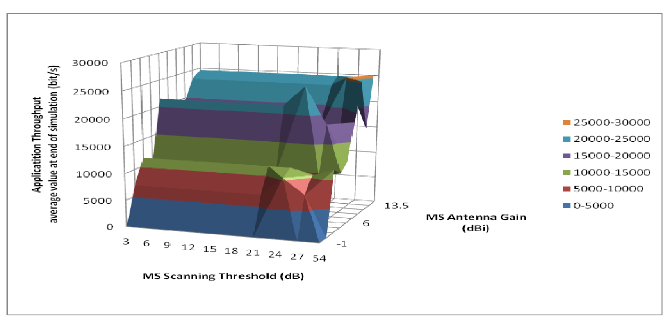

Figure 6. MS Antenna Gain - MS Scanning Threshold -- Decision Space for MS Speed 50m/s

Simulations set: A05B_C_D01 E03 F01_S10 for low speed (s= 10m/s) and A05B_C_D01 E03 F01_S50 for high speed (s= 50 m/s).

Scanning Method: N=4 P=240 T=10.

As expected, the diagrams illustrate the fact that antenna gain has a major effect on the throughput. On the contrary, in this scenario adjusting the scanning threshold for a given value of gain, does not change significantly the throughput, except the high speed scenario (s = 50 m/s) when taking a more sensible scanning threshold (> 21 dB) can bring some throughput raising with 10 – 20%. The explanation is that making the scanning threshold more sensible does not help if the major factor of antenna gain is low. The speed influence is again a worsening one: the maximum throughput that can be achieved for speed of 50 m/s versus 10 m/s is about a half.

These conclusions does not mean that scanning parameters are not important to be adjusted properly, but show that the context is important and in different contexts, scanning activity might be more or less critical.

The two sets of diagrams clearly show the dramatic effect of antenna gain increase on throughput increase, while the variation of scanning threshold is not so significant. For different MS speed values, the density of scanning has more effects that are visible.

C. *Influence of MS scanning method and MS speed*

The following set of simulations experimented different scanning methods (Table 2). N=scanning (frames), P=interleaving (frames), T=iterations.

Simulations set: A05 B05 Cx1-x6 D01 E03 F01_S10-50 (it covers all speed range, from 10m/s to 50m/s).

Table 2 Scanning method parameters

MS scanning method	Cx1	Cx2	Cx3	Cx4	Cx5	Cx6
MS Scanning Threshold (dB)	10	20	30	40	50	60
N (frames)	30	25	20	15	10	5
P (frames)	50	100	150	200	250	250
T	10	10	10	10	10	10

It is seen that Cx1 represents a scanning method having relative large N/P ratio, i.e. the relative time spent with the scanning is larger versus the time spent to transmit the data payload. At the other end of the range, Cx6 has small N/P, i.e. the scanning relative time is less than the time spent for data transmission. On the other side, the scanning threshold has been adjusted as to compensate in a certain measure this scarcity of spanning activity, by taking a higher value of the scanning threshold (60 DB).

Fig. 7 shows an aggregated diagram in which the scanning threshold and scanning interleaving are varied on one dimension and the MS speed on the other dimension. It is seen that for low MS speed the scanning method is not so critical, therefore, a light scanning (small N/P) is sufficient to allow more relative time for data transmission. However, a dense scanning method is very effective for high speed, when mobile is quickly aware about the next BS available, and the low scanning method implies a slow reaction of mobile to communication condition changes.

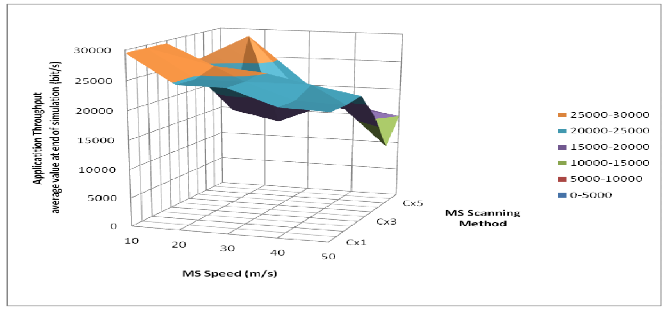

Figure 7. MS Scanning Method – MS Speed – Decision Space

Fig. 8 shows the throughput in two extreme cases in the range experimented: (Cx1- CX6 at s= 10 m/s – left and Cx1-Cx6- at s= 50 m/s – right). It is seen that at s= 50 m/s a more dense scanning is better (Cx1 and Cx3).

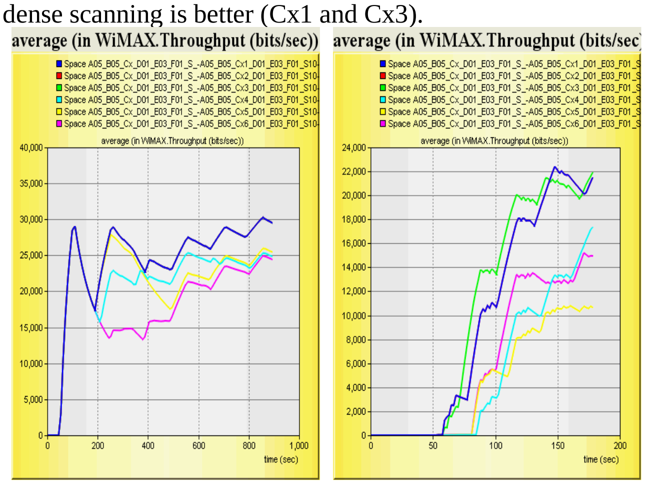

Figure 8. Influence of scanning density, scanning threshold variation and speed on throughput – sample cases

D. *Influence of MS hysteresis threshold and MS speed*

This section studies the effect of the hysteresis threshold values selection when the speed is also varied.

Simulations set: A05 B05 C08 D01-10 E03 F01_S10-50

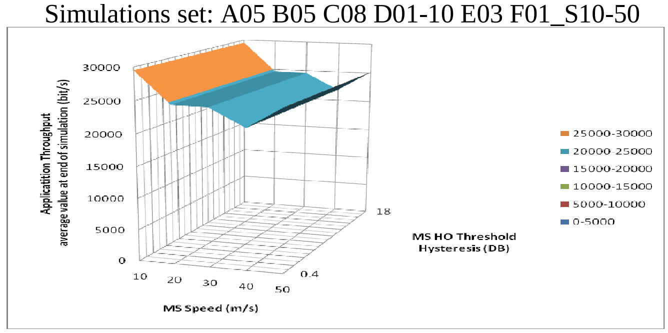

Figure 9. MS HO Threshold Hysteresis - MS Speed – Decision Space

The hysteresis can be used to select BSs as that are suitable candidates for the target BS in a HO. When finding the candidate BSs, the MS (or simulation) may compute the difference between the CINR of the serving BS and the CINR of the potential target BS .The value of this attribute (Hysteresis threshold) specifies the minimum amount by which the CINR of potential target BS must exceed that of

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the serving BS. The value of new signal to noise ratio should be greater with the Handover Threshold Hysteresis than the current value in order that the HO can be triggered. An auxiliary Multi-target Handover Threshold Hysteresis (its value is less than Handover Threshold Hysteresis) can also be used to select among scanned possible target BSes before handover triggering.

As observed in Fig.9, there is no modification for different values of MS HO Threshold Hysteresis, so that parameter has no importance in an environment as that simulated one. That conclusion is applied for that context only; due different network topologies with different WiMAX parameter values could produce different results.

E. Influence of MS Maximum TX Power and BS Antenna gain

This section will study the effect on throughput of the MS Maximum TX Power and BS antenna gain.

Simulations set: A_B05 C08 D07 E03 F_S10 for MS speed 10m/s and A_B05 C08 D07 E03 F_S50 for MS high speed (s= 50 m/s).

A major conclusion, highlighted in both Fig. 10 and Fig.12, is that BS antenna gain has a major impact on MS observed throughput at all ranges of MS TX Power.

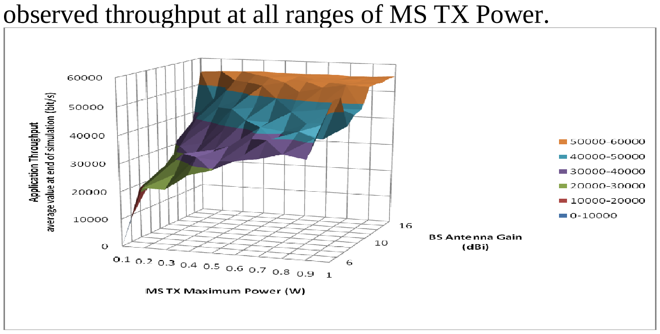

Figure 10. MS Maximum TX Power - BS Antenna Gain -- Decision Space for MS Speed 10m/s

For low speed, the application throughput grows with MS Maximum TX Power increase or with BS antenna gain. There is an important growth with MS Maximum TX Power for low values of BS Antenna gain, which will be less important as the BS antenna gain increase (see the 50000 – 60000) region in the figure.

Sample vertical sections of MS Maximum TX Power-BS Antenna Gain Decision Space for MS Speed 10m/s are presented in Fig. 11, describing the V2I system behavior under effect of BS antenna gain variance.

One can see that at low MS power (left-upper part diagram) the influence of the BS antenna gain is dramatic- which is normal in such low MS power condition. When the MS Maximum TX power is increasing this compensate a lower BS antenna gain and the throughput is better even for lower values of the BS antenna gain. The best results are obtained (bottom-right diagram) for sufficient power at MS (1.0W) and high BS antenna gain g= 16dBi. On the other side is to be observed that sufficient throughput can be obtained with less power at MS (i.e. for P > 0.6W). This can give the possibility to apply policies in adjusting the maximum MS TX power in function of current condition.

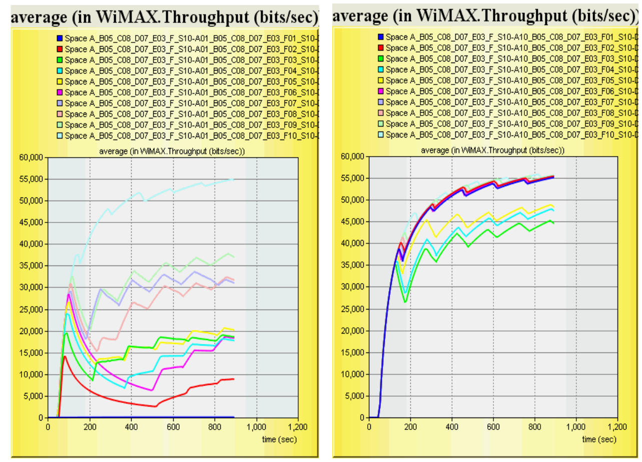

Figure 11. Throughput for different values of MS Maximum TX power and variation of the BS antenna gain (MS TX P = 0.1, 1.0W) s = 10 m/s

For high speed, the application behavior is more complex (Fig. 12).

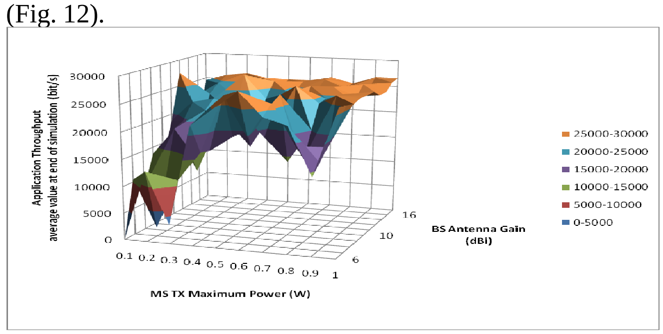

Figure 12. MS Maximum TX Power - MS Antenna Gain -- Decision Space for MS Speed 50m/s

In the simulated scenario (versus network topology and trajectory), there are optimal values for MS Maximum TX Power (ex. 0.5W for BS Antenna Gain -1dBi). These optimal values are different for each BS Antenna Gain value. The mobile could adjust its Maximum TX Power to the value indicated in Decision Space and it will obtain the maximum application throughput. There is no clear dependency between MS Maximum TX Power increasing or BS Antenna Gain and application throughput growth, as obtained for low speed.

The qualitative results for high speed are the same as for low speed, but the overall throughput is significantly lower (roughly twice), even for high MS TX Power and high BS antenna gain.

F. Influence of MS and BS Antenna gains

The MS and BS antenna gains are expected to have major influence on the overall performance.

Simulations set: A05 B_C08 D07 E03 F_S10 for low speed (s = 10 m/s).

For MS low speed (s = 10 m/s) the Fig. 13 diagram shows a rather monotonic increase of the throughput with both BS and MS antenna gain on both dimensions. However a "triangle" in the space (*BS-gain*, *MS-gain*) of saturation (region 50000- 60000) is seen (top-right side) where no

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increasing in throughput is possible; in other words, the BS gain and MS gain "cooperates" and we obtain sufficient throughput if an empirical (approximated) relationship is fulfilled:

$$BS\_gain + MS\_gain > a$$

where limit a can be determined from the figure. This observation gives the possibilities to apply policies to cross-adjust the BS antenna gain and MS antenna gain.

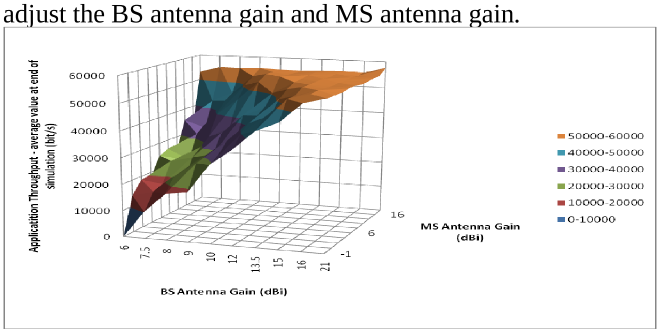

Figure 13. MS Antenna Gain - BS Antenna Gain -- Decision Space for MS Speed 10m/s

The simulations highlights that for high speed (Fig. 14), the application throughput has a approximately constant level at middle range of parameters, where the variance of MS Antenna Gain and BS Antenna Gain has no major effect, as opposite with low speed situations, where that constant level is reached near the highest range of parameters.

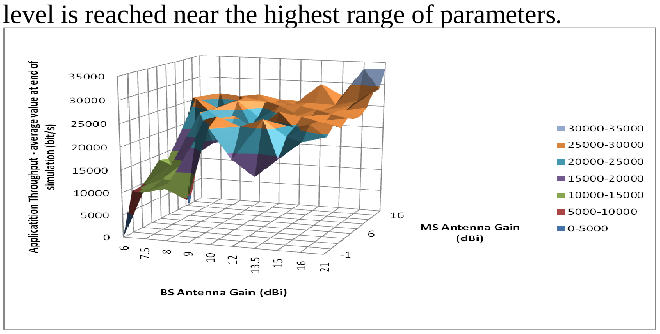

Figure 14. MS Antenna Gain - BS Antenna Gain -- Decision Space for MS Speed 50m/s

If BS antenna gain is g= 9dBi then after at MS g > =10 dBi, we do not get further improvement (left diagram). A similar effect is seen in the right figure for g>=4dBi.

V. CONCLUSIONS

A. Conclusions related to simulations

One important conclusion of the simulation studies is that the antenna gain of MS and BS has major impact on throughput in a large range of other parameter variation (speed, power, scanning threshold, hysteresis threshold, etc.). Having a good antenna gain at both BS and MS is essential in all contexts. This is a reason to use directional antennas, which expose such properties.

As for other parameters (speed, scanning threshold, hysteresis threshold, etc.) the results obtained show that the behavior of throughput versus variation of parameter combinations is not a monotonic one and is context dependent. This conclusion is however natural for a system that has tens of inter-dependent working parameters, but cross-optimizations are possible in the sense that the results of the decision spaces can be used in policies governing the ranging, scanning, HO, etc.

B. Conclusions related to decision spaces method and cross-layer algorithm

The analysis of V2I system behavior on incremental variance of speed, antenna gain, maximum Tx power, and scanning threshold/methods under decision space matrix provides a data base usable for optimization methods/techniques. Each decision space allow not only the combined effect details of a pair of parameters variance, but allow to predict the system behavior for each specific parameter value (see decision space vertical section examples presented in Fig. 11).

Network operator could use such kind of extended simulations for different roads and highway, where the network topology and the road details are known. Vehicles provided with WiMAX terminal capabilities passing these roads could be helped to optimize the communications using cross layer-algorithm based on location and speed prediction from GPS information and optimal parameters set from network operator.

ACKNOWLEDGMENT

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