# An Analysis of Smart Antenna Usage for WiMAX Vehicular Communications

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**Abstract.** WiMAX communications for vehicular use is a topic of significant interest in the research and industry communities, for both V2V (vehicle-to-vehicle) and V2I (vehicle-to-infrastructure) scenarios. This paper presents results of an experimental, simulation-based study, for mobile WiMAX V2I communications for different mobile station (MS) speeds. The scenario results are applicable to both omni-directional and beam forming smart antenna use. This study describes a database consolidation process in order to determine multi-dimensional regions where different lower layer parameters have influence on the overall performance of WiMAX V2I communications. Based on the multi-dimensional graphs, optimal parameter sets and network topology information can be provided by the network operator to vehicular MS, (e.g. a car or a train), providing essential support for the mobile station's smart antenna tracking systems and allow adaptation of the major WiMAX parameters to its speed and network topology.

**Keywords:** WiMAX vehicular, smart antenna, cross-layer optimization.

## 1 Introduction

WiMAX communications for vehicular use has gained continuous attention from the research community, for both V2V (vehicle-to-vehicle) and V2I (vehicle-to-infrastructure) applications. Given the high number of WiMAX physical and MAC layer parameters, that influence the overall performance in mobility scenarios, experimental simulation studies of complex scenarios are very helpful in determining the combined effect of such parameters.

In Ref [4], the authors propose a study of 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 rates over multiple interfaces, uses network information for user locations and used paths for effective and balanced utilization of the available bandwidth [5]. Ref [6] 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

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WiMAX testbed. In Ref [7], mobile WiMAX trials are analyzed to investigate the vehicular downlink performance for a number of on-car antenna configurations.

This paper presents a detailed experimental study related to WiMAX V2I communications using an OPNET™ v14.5 [1] simulation environment. Our aim is 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 OPNET WiMAX simulations results in our work are consolidated in multidimensional graphs, named as: 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 vehicular communications by guiding the tracking and scanning algorithm and controlling the hand-over (HO) decisions between the base-stations.

The research leading to these results are supported partially by the European Community's Seventh Framework Programme (FP7/2007-2013) within the framework of the SMART-Net project (grant number 223937). The SMART-Net (SMART-antenna multimode wireless mesh Network) project [13], based on which the architectural requirements are drawn for this work, has among its objectives, studies and experimental analysis of hybrid mesh networks, including mobility issues. SMART-Net project is developing a heterogeneous access network solution incorporating multi-radio access technologies (RAT) and smart antennas to offer advanced wireless broadband solutions [2][3]. Terminal/user mobility is an integral part of the architecture and it is supported by a mobility management and control framework. The networking technologies considered in SMART-Net are IEEE 802.11x, 802.16x and 802.15x. Specifically micro and macro – mobility are studied and innovative solutions are targeted both for horizontal and vertical handover types. The IEEE 802.16e/WiMAX mobility solutions constitute a major area of work and investigation of the project.

The paper is organized as follows: Section 2 details the scanning, tracking and the HO algorithm for smart antenna use, Section 3 describes the simulations and the decision spaces in the context of smart antenna use. Section 4 outlines the conclusions, identifies a number of open issues and suggests some future work.

## 2 Scanning, Tracking and the HO Algorithm for Smart Antenna Use

The work presented in this paper is a continuation of a set of detailed studies on WiMAX mobility. The initial results have been shown in a study of HO performance for WiMAX mobility in [8], continued with an WiMAX HO conditions evaluation towards enhancement through cross-layer interaction proposed in [9], together with a SIP-based cross-layer optimization for WiMAX Hard HO method, described in [10]. In depth analysis of WiMAX V2I communications are presented in [11].

In this paper, simulation results are consolidated into multi-dimensional regions, where different lower layers parameters have influence on the overall handover performance in mobility scenarios. The BS and MS scanning processes are a combination of omni-directional and smart antenna scan modes designed to adapt the beam selection according to the MS's movement through the network of BSs and to assure the directed beam alignment between the linked MS and BS pairs.

Thus the smart antenna mode, a mapping table termed as scanning table, where the BS's corresponding beam will be used during MS communications with the BS (Table 1). That table will have one entry for each BS: BS ID – corresponding beam – SNR value measured on omni-directional mode.

**Table 1.** Scanning table

| BS_ID | Corresponding beam | SNR_omni-directional mode |
|---|---|---|
| 1 | 11 | 52dB |
| 2 | 1 | 47dB |

The corresponding beams are found when the MS scan is in its omni-directional mode. During that period the MS discovers all BSs within the current coverage area and identifies the corresponding beam/angle for each BS. The first mapping table is updated on each scan.

A second mapping table, named HO mapping table, based on the first one, will provide essential information for smart HO (Table 2). That table will have 6 entries:

- Serving BS ID – corresponding beam - SNR value measured on smart antenna mode;
- Serving BS ID – predicted beam - SNR value estimated for smart antenna mode;
- Back-up BS ID – corresponding beam - SNR value measured on smart antenna mode;
- Back-up BS ID – predicted beam - SNR value estimated for smart antenna mode;
- Target BS ID – corresponding beam - SNR value measured on smart antenna mode;
- Target BS ID – predicted beam - SNR value estimated for smart antenna mode.

**Table 2.** HO mapping table

<table>
<tr><th colspan="2">BS_ID</th><th colspan="2">beam</th><th>SNR_smart antenna mode</th></tr>
<tr><td rowspan="2">Serving BS_ID</td><td rowspan="2">1</td><td>Corresponding beam</td><td>11</td><td>58.2dB</td></tr>
<tr><td>Predicted beam</td><td>10</td><td>60.7dB</td></tr>
<tr><td rowspan="2">Back-up BS_ID</td><td rowspan="2">2</td><td>Corresponding beam</td><td>1</td><td>55.8dB</td></tr>
<tr><td>Predicted beam</td><td>12</td><td>58.3dB</td></tr>
<tr><td rowspan="2">Target BS_ID</td><td rowspan="2">3</td><td>Corresponding beam</td><td>4</td><td>46.9dB</td></tr>
<tr><td>Predicted beam</td><td>3</td><td>49.4dB</td></tr>
</table>

Each corresponding beam value for each BS is taken from the first table. A scanning in smart antenna mode along that beam will provides the related SNR value.

The serving BS is the BS where the MS is currently connected. The back-up BS is the BS where the MS could be connected in the case of the serving BS having unexpected unavailability. That BS is on coverage area, and MS keeps the related data for back-up situations.

The target BS is the BS chosen as the target for the next BS. Due to the added gain obtained during the smart antenna mode, the MS has a larger effective coverage area than a standard omni-directional antenna. It can be noted that in these situations, the number of HOs could be advantageously decreased, based on a smart HO algorithm. The MS will decide to skip some BSs along its trajectory, so the target BS could be different from next BS with maximum SNR.

The BSs locations are available from the network operator using periodical updates. The update mechanism is outside the scope of this paper. However, it is believed the solution proposed in [10] could also be used successfully for the information exchange update routines.

That is, based on GPS information, the MS identifies its geographical position, direction, speed, and computes the angle of the beam for each BS under its coverage. Each current beam assignment is made during the scanning process and recorded into first mapping table, the MS will use the computation results to predict the angle/beam for the next position/scanning time stamp. The scanning time stamps, as mentioned, are determined one at a time, and the MS position will be established and related to the next scanning time stamp reference.

Simulations have demonstrated that the proposed predicted beam selection process is very useful, especially for high speed mobile users, when the corresponding angle for each BS is changing quickly and there is a need for a dense scanning process. In fact, based on predicted simulation results, it is noted that the scanning duration could be decreased, so moderating the application's throughput. The scanning, tracking and smart handover for a mobile user using a smart antenna is depicted in Fig. 1.

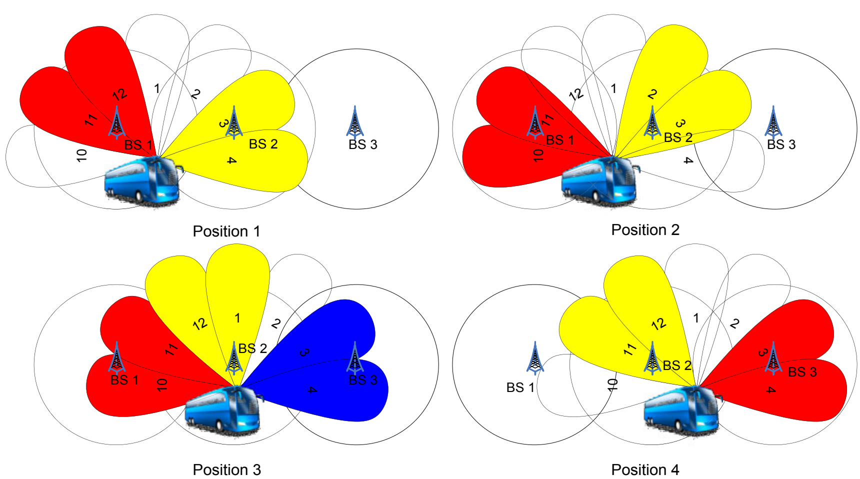


**Fig. 1.** Serving BS, scanned BS and HO target BS for smart antenna mode

Position 1:

- MS on BS_1 coverage for both smart antenna and omni-directional mode, next to BS_2 coverage in omni-directional mode;

- MS attached to BS_1, keeping BS_2 as back-up;
- Serving BS: BS_1, corresponding beam: 12, predicted beam: 11 (red);
- Back-up BS: BS_2, corresponding beam:4, predicted beam: 3 (yellow);
- If in omni-directional mode, MS should initiate the scanning process. In smart antenna mode, BS_1 still far from HO SNR threshold, so the target BS is not available at that moment;
- Target BS: not used.
- However, in case of forced HO due unexpected serving BS failure, the MS will initiate HO to the back-up BS, currently BS2.

Position 2:

- MS next to BS_1 coverage limit for omni-directional mode, and on BS_2 coverage for omni-directional mode;
- MS attached to BS_1, keeping BS_2 as back-up;
- Serving BS: BS_1, corresponding beam: 11, predicted beam: 10 (red);
- Back-up BS: BS_2, corresponding beam: 3, predicted beam: 2 (yellow);
- If in omni-directional mode, MS should initiate the HO process, serving BS: BS_1, target BS: BS_2.
- In smart antenna mode, BS_1 still far from HO SNR threshold. However, the scanning process should be started soon (position 3);
- Target BS: not used.

Position 3:

- MS on BS_1 coverage for smart antenna mode only, on BS_2 coverage for omni-directional, and on BS_3 coverage for smart antenna mode;
- MS attached to BS_1, keeping BS_2 as back-up;
- BS_3 available on smart antenna mode and selected as possible HO target;
- Serving BS: BS_1, corresponding beam: 11, predicted beam: 10 (red);
- Back-up BS: BS_2 , corresponding beam: 1, predicted beam: 2 (yellow);
- Target BS: BS_3, corresponding beam:4, predicted beam: 3 (blue);
- BS_1 near HO SNR threshold, so MS should initiate the HO process: serving BS: BS_1, target BS: BS_3. the HO is a smart one, due BS_2 was skipped from HO process.

Position 4:

- MS on BS_3 coverage for smart antenna mode and next to coverage limit for omni-directional mode, on BS_2 coverage in omni-directional mode;
- MS attached to BS_3, keeping BS_2 as back-up;
- Serving BS: BS_3, corresponding beam: 4, predicted beam 3 (red);
- Back-up BS: BS_2, corresponding beam: 12, predicted beam: 11 (yellow);
- Target BS: not used.

Moving through the BS network, the MS will discover BS_4, and the conditions from Position 1 will be encountered again, having BS_3 as serving BS and BS_4 as back-up BS (not shown in Fig.1).

Fig.2.A and B present some advantages of smart antenna use. From fig.2.A, it can be seen the extended coverage effect obtained due to smart antenna use. The first graph shows the application throughput when MS is using an omni-directional antenna, 6dBi gain (blue). There are some communication gaps, due to lack of coverage. On the same conditions, but when MS is using a smart antenna with 13.5dBi cross-over gain (red), and 16dBi peak gain (green), the application throughput is completely different, as seen in the second and the third graph.

On the fig.2.B, the MS has an omni-directional antenna, 6dBi, on first graph (blue), and a smart antenna with 13.5dBi cross-over gain (red), and 16dBi peak gain (green). Even though the application throughput seems to be the same for all three graphs, the extended coverage allows to MS a smart HO decision, so two unnecessary HO are avoided (third graph-green).

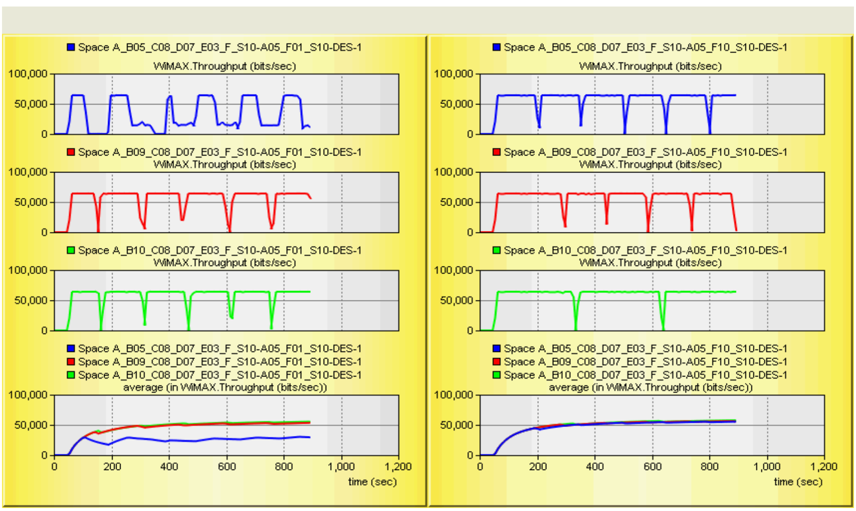


**Fig. 2.** A and B Advantages of smart antenna use: extended coverage –left (A) and smart HO-right (B)

## 3 Decision Spaces

A smart antenna, of cylindrical type, 12 beams, was considered, detail beam patterns for which are provided by Plasma Antennas (see [12]). It can operate on both omni-directional and beam selected modes (named smart antenna mode for easy reference).

The smart antenna has the following gains:

- Omni-directional gain, with all 12 beams active, acting as a standard omni-directional antenna: 6dBi;
- Smart antenna cross-over gain, measured between two adjacent beams: 13.5dBi;
- Smart antenna peak gain, measured on the direction of the active beam: 16dBi.

Given the high number of WiMAX physical and MAC layer parameters influencing an inter-dependent mode, the overall performance in mobility scenarios, a detailed experimental study of WiMAX V2I communications has been performed, in order to determine multi-dimensional regions where different lower layer parameters have influence on the overall handover performance.

The simulations results are consolidated in multi-dimensional graphs, named decision spaces. These decision spaces present in aggregated form the communications performance obtained in a WiMAX V2I mobility scenario, related to a specific trajectory. Each multi-dimensional graph - decision space is consolidating the results of 100 simulations, each simulation corresponding to one parameter pair from Table 3.

**Table 3.** Main WiMAX parameters analyzed on simulation scenarios

| | 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 |

Considering only two parameters as variables, one decision space is defined for each MS speed value (10m/s, 20m/s, 30m/s, 40m/s and 50m/s). These decision spaces provide an overall estimation about the MS communication capabilities on the related network conditions (network topology, BS locations, antenna gain, Tx maximum power), combined with mobile constrictions (MS speed, scanning method, antenna gain, Tx maximum power).

Since the network conditions remain unchanged on usual operations, MS could use the decision spaces corresponding to its speed to adapt its own parameters (scanning method/parameters, Tx maximum power). As example, Fig. 3. presents four decision spaces (DS1..DS4), corresponding to the following situations:

- MS maximum Tx power variable 0.1..1W;
- MS antenna gain fixed: 6dBi for DS1 and DS 3, and 13.5dBi for DS2 and DS4;
- MS scanning threshold fixed: 24dB;
- Scanning method fixed: N=4, P=240, T=10, where N=number of scanning frames, P=number of interleaving frames, used for data, T=number of N_P cycles;
- MS HO threshold hysteresis fixed:12dB;
- BS maximum TX power fixed: 1W;

- BS antenna gain variable: 6…..21dBi. That parameter is unchanged for operator, but in can be different from one BS to another, so for each BS is corresponding a vertical section in the decision space, according with BS antenna gain value;
- MS speed fixed for each decision space: 20m/s (72km/h) for DS1 and DS3, and 40m/s (144km/h) for DS2 and DS4.

The DS1 and DS2 could be used for MS with an omnidirectional antenna, moving with 20m/s –DS1, and 40m/s respectively -DS2, and the DS3 and DS4 are for an MS with a smart-antenna as in Ref [12], at the same speeds.

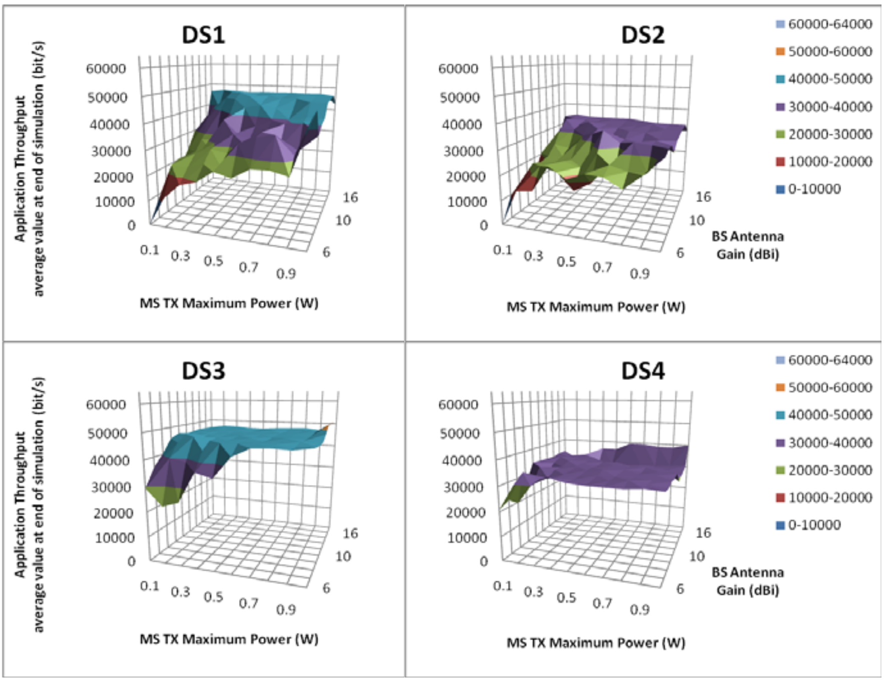


**Fig. 3.** Decision spaces for MS with omni-directional antenna (6dBi) and smart antenna (cross-over gain 13.5dBi), moving with 20m/s, and 40m/s respectivelly

Accordingly, with the system behavior described in DS1 and DS2, the MS communication capabilities are decreasing with the speed. At lower speeds (20m/s), the increase of the MS Tx maximum power allows a significant increase in application throughput. At higher speeds (40m/s), the increase is not so significant, and after a specific value of MS maximum Tx power, the application throughput reaches a maximum, so bigger values for MS Tx power will have almost no additional effect on the communication capabilities. Knowing that threshold value, the MS could limit its Tx power so reducing the possibility of interference.

Analyzing DS3 and DS4, the same communication capabilities decrease is observed. However, due to smart antenna use, the coverage area is bigger when compared to omni-directional use, and the application throughput reaches maximum for small value of MS

Tx maximum power. Again, knowing the related threshold value, MS could limit its Tx power, and could gain an important reduction in potential interference.

A DS1 against DS3 comparison highlights the importance of smart antenna use. The maximum communications capability is dramatically increased using smart antennas, and that maximum is reached for low value of MS Tx power. Fig.4 compares the vertical section through DS1 and DS3, analyzing the benefits of smart antenna use for a MS moving with 20m/s on the two situations (omni-directional antenna, smart antenna).

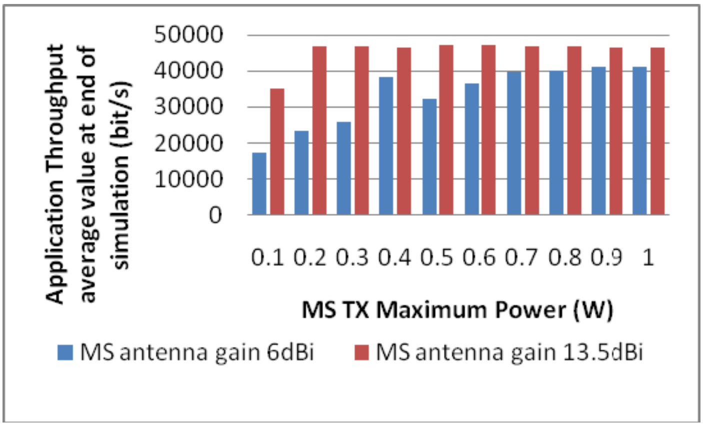


**Fig. 4.** Vertical sections through DS1 and DS3, showing the benefits of smart antenna use. MS speed=20m/s

According to these sections, a maximum value is obtained for omni-directional antenna use for MS Tx power=0.4W, with a decrease from 0.5W to 0.7W when the initial maximum is reached again. On contrary, using a smart antenna, the maximum is obtained for MS Tx maximum power=0.2W and remain steady. The MS could stop increasing its Tx maximum power, and look for additional fine tuning, as smart HO methods, to improve further its communication capabilities.

# 4 Conclusions

In conclusion, this research has demonstrated through a set of OPNET simulations that optimal parameter sets, obtained from the decision spaces described above, can be provided by a network operator to mobile stations (MS), helping it to adapt dynamically its behavior and to obtain the maximum throughput possible from the network at different speed, antenna gain, maximum transmission (Tx power), and scanning values.

With regard to future research, it is recommended that the use of smart antennas on both the BSs and MSs be considered for high user densities and more complex journeys using extensions of the current OPNET representations. In this way, the problems of co-channel interference may be assessed and protocols developed to facilitate dynamic beam and power management for both the mobile users (i.e. the MSs) and their WiMAX access points (i.e the BSs), thus offering greater frequency re-use, better overall coverage and the possibility of increased cell sizes in sparsely populated areas. Moreover, the use of smart antennas for BSs, in the context of a highway or other transport infrastructure, will offer greater benefits in terms of coverage and reduced interference.

However a number of open issues remain, such as BS beams synchronization with MSs current positions, (possibly requiring GPS timing information), sub-frames allocation, BS resource allocations in respect of smart handover protocols.

Furthermore, advances in smart antenna technology, such as electronically selecting beams in both azimuth and elevation, especially at BSs, should also be incorporated in the OPNET HO simulations to quantify the resulting gains in performance, quality of service and coverage. The introduction of LOS blockage caused by buildings and natural objects such as trees should also be introduced to access the resilience of the HO process.

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