ASSESSING CAPABILITIES OF COMMERCIAL WIMAX NETWORKS FOR DELIVERLING REAL-TIME SURVEILLANCE VIDEO TRAFFIC IN UPLINK

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Abstract. Streaming video in uplink is an interesting opportunity for network operators for capitalizing unused part of bandwidth (due to Internet asymmetry). The uplink seems not optimized nowadays due to lack of business cases. The main challenge however is bursty and unpredictable nature of wireless channel observed especially as mobility comes into play in current broadband networks. That is why in this paper, we have approached the diagnosis of commercial mobile WiMAX network towards the capabilities of assuring real-time video in uplink direction. We present results of drive tests showing that delay in WiMAX networks for LOS-NLOS (Line of sight - No n line of sight) mobile conditions is largely contributed by uplink direction (60-90% of RTT (Round trip time)) whereas downlink directions hardly ever exceeds 40ms. We show that enabling MIMO-A(Multiple Input Multiple Output) can decrease delays by 100ms in NLOS conditions and decrease delay variation by up to 90%. For each of tests we have presented exact probabilities of particular modulations involved based on channel realizations.

1 Introduction

Growing installations of IP (internet protocol) cameras and need for surveillance cameras with better video quality is driving the demand for IP based video surveillance systems, globally [19]. Still the availability of networks with sufficient resources i.e. coverage, signal strength and quality - in virtually every place is limited to enable high data rates for video feeds in remote locations. There are still number of geographic locations where mobile networks coverage is degraded - e.g. rural areas, highways - to some legacy cellular technologies like e.g. GPRS or UMTS. On the other hand the performance of cellular networks is continuously improving. Based on crowdsourced data from the OpenSignal [16] it can be seen that network

performance of so called 4G networks has significantly improved compared to its predecessors (see Tab. 1). Still even in such networks supporting real-time applications poses many challenges, including limited bandwidth, coping with bandwidth fluctuations, and lost or corrupted data. These conflictual requirements - high data volumes and limited resources - emphasize the need for efficient codecs but also reasonable optimizations in the networks combined with cross layer based congestion control and adaptable control. That is why among all the MITSU project [10] has been defined to deliver solutions to overcome these limitations in mobile broadband networks for surveillance and multimedia scenarios. The observation that is main motivation of the MITSU project is that a network delivering video in a heterogeneous wireless environment with unpredictable and bursty channel usually leads to increased requests for retransmissions increasing bandwidth and energy and also creating inherent congestion on the network.

Tab. 1: Cellular networks performance - sample statistics (adapted from [16])

Country	Delay [ms] (2G/3G /4G)	Ul through-put [MB/s] (2G/3G /4G)	Reliability [%] (2G/3G /4G)
Poland	838/596/88	-/0.7/3.9	75/82/93
Germany	909/639/42	-/0.4/2.7	79/81/85
USA	791/283/44	-/0.3/2.6	66/79/79

Mechanisms that deal with those issues in the data link and physical layer are ARQ and HARQ ((Hybrid)Automatic Repeat reQuest). ARQ schemes provide high reliability when the channel is good or moderate. However, for error prone channels, the throughput drops due to increased frequency of retransmissions. In order to counter this effect, hybrid ARQ schemes are used that combine FEC(Forward error correction) with ARQ schemes [11]. From the commercial perspective number of WiMAX networks today mostly provides Internet access services based on downlink resources and best effort service (responding to the demand of its subscribers). WiMAX base stations (BSs) complement cellular deployments especially in places of worse coverage of cellular networks. The main use-case motivating the creation of the paper is delivery of mobile video streaming of CCTV (Closed Circuit TeleVision) video in uplink direction as the radio resources in this direction are usually underutilized while there exists evidence that many end-users are interested in delivering mobile CCTV videos from the field in efficient way for surveillance purposes [10]. That is why authors performed numerous field tests trying to analyze the real capabilities of the technology towards delivering surveillance video. In this paper we perform a diagnosis of commercial WiMAX network of local operator in Poland. We collect network performance characteristics using measurement toolkit which we have developed and described in our previous paper [3]. This paper is organized as follows: Section 2 presents related works concerning video streaming in the context of mobile WiMAX. Section 3 introduces reference scenario motivating the research. Section 4 briefly shows test configuration that was used with approach to measurements. Detailed description of the measurements performed on the commercial network as well as results are described in Section 5. Conclusions and future work are provided in Section 6.

2 Related Work

Our previous work has concentrated on validating performance and fidelity of portable measurement environment that we have created using off-the-shelf components and software [20]. We claim that for the needs of local mobile operators the use of open-source, affordable cost and robust solution for performing field tests is essential success factor on the way to network diagnosis and further optimizations. Although there exist methods of video

quality estimation for streaming traffic [7] or methodologies to evaluate the network performance the area of target recognition tasks from video feeds is currently in its intense growth. That is why we assume that evaluating real-time video streaming is neither simple nor clearly defined. In [4, 9] authors propose a video streaming system that supports streaming in different conditions aiming at low-latency transmission over limited bandwidth network. Requirements for target video stream delivery with a sufficient quality to be correctly analysed by both human-based or computer-based video surveillance layers are analysed. To this aim authors propose an optimization of the streaming process with an adaptive control of the streaming parameters. Recent work of standardization organizations and groups like e.g. VQEG [20] and ITU-T P.912 [8] shows the trends of also adjusting methodologies for evaluating video quality for the target recognition tasks. The challenging part here is that calculating PSNR (Peak signal-to-noise ratio) or measuring any other distortion metric (blurriness, blocking effect, etc.) of the video frame is not necessarily the most accurate way to decide if target recognition would be successful. Authors in [21] show that real-time streaming over mobile WiMAX networks is often delay sensitive but loss tolerant. Moreover different segments of media stream (i.e. code stream) have significantly different perception importance and these different code streams may require significantly different error protection. Thus multimedia streaming optimization over WiMAX networks can be mathematically generalized as a delay bounded quality optimization problem. Such problem is cross-layered in nature as it involves application layer distortion analysis in image/video codec as well as network/radio resource allocation strategy design in WiMAX. Capabilities of application layer distortion are codec-driven and can be adaptively controlled while keeping ratedistortion optimized. Multimedia applications, such as voice and video streaming, can typically tolerate 5-10% packet

loss while still maintaining acceptable quality [2]. For example, various error resiliency schemes employed by H.264/AVC [18] can be used to tolerate PER (Packet Error Rate) of up 20% [17, 6]. Still what is crucial for appropriate analysis of video feeds performance is that it requires the use of time-varying instantaneous Block Error Rate (BLER) in a fading channel (not averaged BLER), since the bursty nature of the errors has a detrimental effect on video quality, as shown in [13]. Authors in [1] show that link-layer retransmissions add reliability and increase the video streaming quality only when the traffic volume is far below the network capacity limit. Allowing simply one retransmission significantly improves the video quality over when no retransmission is used. However, increasing the retransmission limit beyond one or two does not generate significant performance gain. The same behavior is reported in [13]. Of course the higher the level of retransmissions the lower the number of admitted connections and higher the delays (but bounded losses). Thus authors in [12] study the effect of ARQ retransmissions on packet error rate, delay, and jitter at the application layer for a real-time video transmission at 1 Mbps over a mobile broadband network. The effect of time-correlated channel errors for various Mobile Station (MS) velocities is evaluated. In the context of mobile WiMAX, the role of the ARQ Retry Timeout parameter and the maximum number of ARQ retransmissions is taken into account. Similarly in [14] authors show effectiveness of each modulation and coding scheme (MCS) given a particular channel SNR (signal-to-noise ratio) (i.e. 12dB and 16dB). They focus on transmitting HD (High Definition) video in downlink direction and use H.264 encoder with video frames of 1024B service delivery unit (SDU). For ARQ lifetimes in the range 10-50ms (i.e. 2-3 retransmissions) the goodput drops for higher order MCS modes due to the high PER and the subsequently large number of retransmissions that occur. On the other hand for ARQ with 4 retransmissions QPSK 1/2 provides near zero BLER for

SNR higher than 18dB. Authors define PSNR/Hz metric that is used to choose the best MCS and block lifetime parameters in terms of target video quality and channel usage for any given mean channel SNR. Complementarily authors in [15] study a single cell performance of the WiMAX with ARQ with subscribers placed in disadvantaged channel conditions. They evaluate influence of multiple connections on performance of the network with ARQ and without it. Authors claim that studying ARQ in network with less than 4 subscribers will not bring much improvement over the non-ARQ case. The highest benefit of using ARQ is seemingly increased throughput and better jitter as number of connections reaches 20. As regards delay behavior at 20 subscribers it doubles as compared to its non-ARQ counterpart. It is possible to control a balance between the desired delay and loss through e.g. a combination of techniques like forward error correction, automatic repeat request, "MAC PDU" (MPDU) aggregation, and minislot allocation like in [11]. Alternatively studies on scheduling services in WiMAX e.g. [22] show that although use of UGS (Unsolicited Grant Service) guarantees best delay performance, the rtPS (Real-Time Polling Service) service could utilize the BS resources more efficiently and flexibly, trading-off between packet transmission performance and BS resource allocation efficiency. Thus to summarize the above analysis it is evident that especially for life video a trade-off must be made between acceptable video quality and latency. This way authors focus on the aspects of delay and quality tradeoff in presenting the diagnosis of the network for delivering surveillance videos.

3　Reference Scenario

For the needs of this paper we assume surveillance system is set up in remote location with limited existing infrastructure. Moreover in this kind of scenarios it is usually important to cover as much area with as little equipment and additional infrastructure, as possible. Therefore in such setups the uplink bandwidth has to be shared between multiple cameras and can be considered a scarce resource. The wireless link considered for the remote scenarios is the IEEE 802.16e standard-compliant network (WiMAX)as it is often considered last-mile access solutions. The target codec considered is H.264 and the bitrates are assumed as low as 128 kbps up to 1Mbps. This is due to the assumption that not all the video has to be sent all the time and at the best quality. This reflects the shift in video processing paradigm (as is the case with FP7 ARENA project), as for the surveillance scenario in remote location shifting some of the task to the remote node (instead of the centralized node like command and control room) may result in increasing the system-as-a-whole capacity. For remote locations, where the monitored area is large, the framerate may also be variable and go to extreme as low as 0.5-1 FPS(Frames per second), depending on the field of view (FOV), pixels per meter (PPM) and the operational requirements. Setting appropriate FOV/PPM/FPS relations becomes much more challenging for surveillance solutions considering nomadic and mobile nodes (e.g. surveillance camera on truck/car vs. multiple parking layouts). However such optimization is out of scope of this paper. For this surveillance scenario focus will be put on scenarios including stationary (e.g. fixed cameras) and nomadic (e.g. car on a parking lot) nodes [10].

4　Measurements configuration

We were performing the tests - both mobile and stationary - in WiMAX 802.16e network utilizing the center frequency of 3.5GHz (i.e. licensed spectrum) with only one base station (BS) serving the network. In order to compare network performance for different bit rates more easily, we used constant bit rate (CBR) equal to either 128Kb/s or 1024Kb/s in order to mimic the almost con-

stant output traffic from transcoder at the remote location. Transcoder is assumed as the traffic regulator to mitigate channel effects in the access network. We have selected such rates as this is the range that represents expected target videos from cameras. Moreover, we carried out tests using default best effort QoS class most of the time and occasionally using the rtPS class to verify network performance depending on the WiMAX classes. We performed tests with most popular modems (Teltonika GM6235 and GreenPacket DX 350). Teltonika enabled us to retrieve the key performance indicators (Signal Strength, Signal Quality, instantaneous uplink and downlink modulation, downlink and uplink traffic speed, GPS position of mobile terminal i.e. the measurement laptop) in an automated manner via API (Application Programming Interface) calls. In case of drive tests we have used a laptop with dedicated external antennas (with magnet mounting to the rooftop) connected through a cable to the miniPCI modem. Tab. 2 below shows detailed settings of BS according to which we have carried out measurements.

For the mobile tests where we evaluated HARQ/ARQ behaviour we have used the Netviewer application to collect snapshots of various performance counters available in BS through its web management GUI (graphical user interface) (which was only the case for the lab tests). Thus the Netviewer traffic was mostly flowing in the downlink direction when we were collecting statistics (HARQ counters) while in the field.

5 Results

One of the most important stages of our work was conducting research activities on well established WiMAX network. Unfortunately, because of commercial nature of tested network, we were unable to get full control over BS settings or estimate exact level of traffic generated by other users during the measurements. Additionally, majority of user's activities is focused around downlink

Tab. 2: Base station settings

Parameter	Value
OFDMA	
Carrier frequency	3,5 GHz
Frame length	5ms
Channel bandwidth	7MHz
Guard interval	1/8
Duplex Method	TDD
Permutation	PUSC
DL/UL ratio & DL capacity	17/15
MCS Modes	QPSK 1/2, 3/4 16QAM 1/2, 3/4 64QAM 2/3, 3/4, 5/6,
MAC	
ARQ feedback/window size	1024
ARQ block lifetime	25ms
QoS Scheduling scheme	BE (rtPS only where indicated in text)
ARQ block size	128
ARQ-DELIVER-IN-ORDER	YES
ARQ Sync-loss	600ms
ARQ Purge-timeout	160ms

traffic. Therefore, the commercial network that we were able to use was optimized for downlink direction, which could potentially lead to somehow disproportionate results for uplink. Fig. 2 presents the overall signal coverage of tested BS, where green color indicates good signal quality, yellow indicates mediocre signal quality and red indicates poor signal quality. Conducted tests were divided into two groups: stationary measurements together with BS coverage tests and mobile tests. Each of the tests will be described in details below.

Stationary measurements

Stationary measurements were performed in spots with very good signal quality, where the signal strength indicator i.e. CINR (Carrier to Interference-plus-Noise Ratio) hovered around 90-95% level. The first set of tests (A) was conducted approximately 1,5km from the BS and the

second set (B) was carried out near the BS (about 70 meters off the station). Fig. 3 below shows the exact positions of measurements and their relative distance from the BS. It is worth noting, that in both locations we observed very similar results for both traffic directions, indicating that at the given distance from BS there aren't experienced any major disruptions. In the downlink direction, the average delay oscillated around 16ms with the standard deviation of ca. 2ms. Also the packet loss was negligible both in 128kb/s and 1024kb/s bit rates scenarios. Most of the time (nearly 90%) the modulation that was used, was the QAM64-ctc 5/6 modulation. We did not notice any major performance differences between modems we used i.e.: Teltonika and Greenpacket. As for the uplink direction, we noticed slightly higher delays and average variation compared to the lab environment (network without real users) conducted in our previous work. It was clear that Greenpacket showed slightly better performance when it comes to delay metrics than Teltonika modem. Tab. 3 and Tab. 4 show the overall results from the stationary measurements of delay metrics and modulation characteristics respectively. As we can see on the Tab. 3 below, the average delay of Teltonika with 128kb/s bit rate exceeded 110ms, while with the use of Greenpacket packets reached their destination after approximately 80ms. Moreover, it is worth noting that for the higher bitrates in uplink, delay metrics show lower average delay. Additionally, the modulation used for each transmitted packet was tracked. Based on this metrics, we have been able to calculate the percentage of time of which specific modulation was used during the whole measurement as well as how frequent the modulations were transitioning between each other. Fig. 1 shows the method how every transition for each packet was calculated. In that particular example, there are 2 transitions from QPSK-1/2 to the same modulation, and 1 transition from QPSK-1/2 to QAM-64. The sum of each transitions are then divided by all transitions occurred in a whole measurement. Thus in this example

the QPSK-1/2 transition occurred in 2 of 3 cases. Such result is presented then in percentage metrics and represents the overall time share of which transition of modulation occurred.
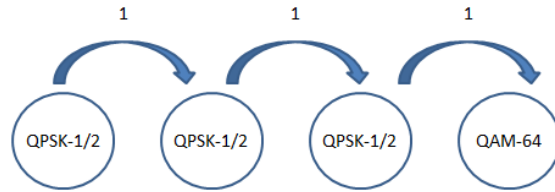

Fig. 1: Example of modulation transitions

Tab. 4 shows the average time share of each modulation used during the measurement. As can be seen, the only modulation that has been used was the QAM64 modulation, only transitioning sometimes between QAM64-ctc-5/6 and QAM64-ctc-3/4 modulations, suggesting very good radio link quality at the places where we performed measurements. Results of delay measurements proved the trend of decreased delays with increased throughput, which was estimated in our previous work. While this time we used only two bitrates 128 Kb/s and 1024 Kb/s it can be clearly seen that delays are much smaller with higher throughput, just as it was proven in our previous work. Therefore we ensured that mentioned trend is not only misbehavior that took place in lab environment, but is present in real commercial network as well. Fig. 4 below presents a comparison of delay values for different bitrates. Each measurement was done for 128 Kb/s and 1024 Kb/s bitrates and repeated 3 times. As we can see both for Teltonika modem (Tel1/2/3) and Greenpacket modem (Gre1/2/3) delays are visibly smaller for higher bitrates. This behavior seems to originate in the power saving class for best effort traffic (PSCI). Most probably for lower rates in uplink there is enough room for modem's TX circuitry to schedule sleep intervals.

But this would need to be validated in future research. This behavior however is no longer seen so clearly in the mobile tests where delays seem to increase significantly
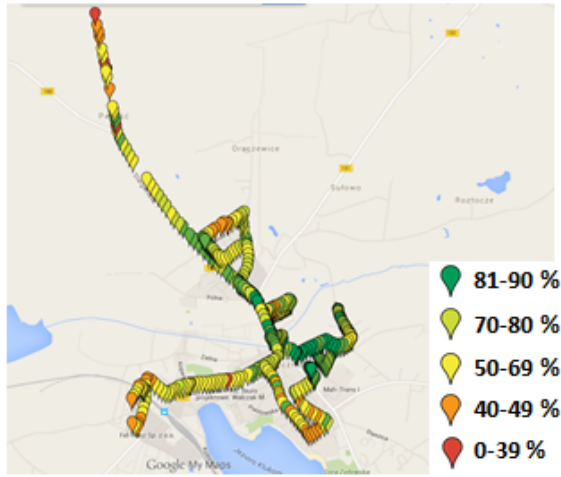
Fig. 2: Coverage of the tested WiMAX BS (percentage signal quality level based on CINR from the drive tests)

and they are more equal between tests. Additionally we have performed a series of tests in order to compare such behavior with each of QoS classes that are of interest: best-effort and rtPS. Our measurements proved that mentioned trend is repeated in measurements with both classes with nearly same results, although according to standards rtPS should apply PSC II with constant sleep interval.
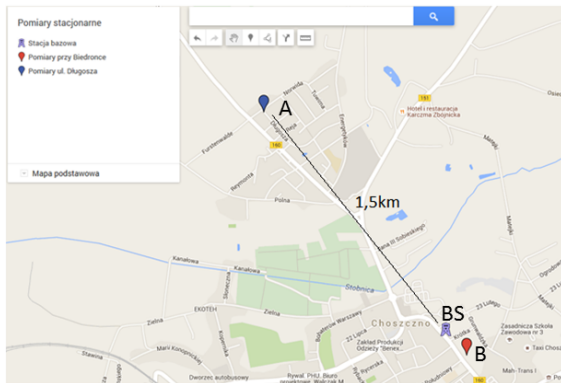

Fig. 3: Location of stationary measurements

Measurements addressing the path from "B" to "A" showed that with increasing distance of antenna from the BS the more robust modulation was used in order to maintain connection and not utilize too much power. Tab. 5 below shows that the system switched between different

Tab. 3: Overall delay results of the stationary uplink measurements

Stationary Uplink - Location A	Avg Delay	Std Deviation	Packets received	Packets lost	Overall	Packets lost ratio
Teltonika 128 kb/s	110,97	61,94	2145	7	2152	0,3%
Teltonika 1024 kb/s	72,47	55,93	16677	59	16736	0,4%
Greenpacket 128 kb/s	82,04	29,30	2159	2	2161	0,1%
Greenpacket 1024 kb/s	57,37	26,81	16708	34	16742	0,2%
Stationary Uplink - Location B	Avg Delay	Std Deviation	Packets received	Packets lost	Overall	Packets lost ratio
Teltonika 128 kb/s	104,32	58,92	2154	1	2155	0,1%
Teltonika 1024 kb/s	58,19	46,78	16624	12	16736	0,1%

Tab. 4: Modulation characteristics of the stationary measurements

Measurement	qpsk-ctc-1/2	qpsk-ctc-3/4	qam16-ctc-1/2	qam16-ctc-3/4	qam64-ctc-2/3	qam64-ctc-3/4	qam64-ctc-5/6	Transitions
A 128 kb/s	0,00%	0,00%	0,00%	0,00%	0,00%	6,24%	93,60%	0,16%
A 1024 kb/s	0,00%	0,00%	0,00%	0,00%	0,00%	16,65%	83,06%	0,26%
B 128 kb/s	0,00%	0,00%	0,00%	0,00%	0,00%	9,82%	89,75%	04,3%
B 1024 kb/s	0,00%	0,00%	0,00%	0,00%	0,00%	7,57%	92,37%	0,06%

modulations only for 1,76% of the measurement time, while the modulations are more spread between various modulations.

Tab. 5: Modulation characteristics during the BS coverage test

Measurement	qpsk-ctc-1/2	qpsk-ctc-3/4	qam16-ctc-1/2	qam16-ctc-3/4	qam64-ctc-2/3	qam64-ctc-3/4	qam64-ctc-5/6	Transitions
Bs coverage	31,67%	9,58%	11,73%	15,49%	0,34%	7,72%	21,70%	1,76%

Mobile tests

For a purpose of mobility tests, we have chosen an area located approximately 1,5km from the BS. One mobile test consisted of a single lap at a constant speed of 15km/h or 30km/h. Note, that such tests did not last the exact same amount of time, as it was in stationary measurements. Single lap was repeated 3 times to avoid any potential measurement errors that might have been occurred due to momentary deviations from the average network behavior. The main factors that influenced our choice of tested area included:

- Different signal strength levels throughout a whole lap. By one lap we were able to gather measurements in both perfect network conditions as well as

bad conditions.

- Ease of test execution. Chosen place was a residential area without much road traffic that could be problematic for mobile tests performance.

As in stationary measurements, we were able to gather information about signal strength level, delay metrics as well as modulation characteristics. Tab. 6 presents delay results from the tests in the uplink direction. As we can see, we have encountered weak network conditions with average delay values up to nearly 500ms. Also the high values of standard deviation indicate that variability of the signal quality was very high, causing significant delay spikes (due to intense operation of ARQ/HARQ mechanisms). In addition, we have observed high values of packets lost, especially for 1024kb/s bitrates where almost 30% of packets were lost. The measurements show interesting trend with modulation changes. Fig. 5 presents signal quality levels along one lap during mobility tests. As we can see during the test, modem experiences spectrum of signal levels from good signal at the start of the measurement, which is denoted with green color then weak and poor signal resembled by orange and red colors respectively.
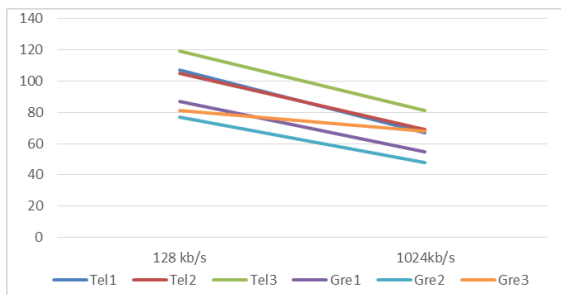

Fig. 4: Uplink delay (in milliseconds)

It is worth mentioning, that the worst level of signal quality that we encountered was 30% (CINR = 9dB) in non-line of sight (NLOS) situations while the car was covered by nearby buildings.

Tab. 6: Overall delay results of the mobile uplink measurements

Mobile Up-link	Avg Delay	Std Deviation	Packets received	Packets lost	Overall	Packets lost ratio
15 km/h 128 kb/s	395,05	372,47	2518	402	2920	13,8%
15 km/h 1024 kb/s	482,66	435,87	8414	3069	11484	26,7%
30 km/h 128 kb/s	363,65	333,18	1509	225	1734	13,0%
30 km/h 1024 kb/s	472,87	457,63	5935	2141	8077	26,5%

Fig. 6 presents modulations encountered along the way in the uplink direction, where the green indicates QAM64-ctc-5/6 modulation which is the highest possible while red indicates most robust QPSK-ctc-1/2 modulation. As can be seen interestingly, modem is unlikely to change modulation used even if radio statistics are getting better. When comparing those two figures, it seems that best modulation appears at start of measurement in best radio conditions and quickly decreases to worst when radio conditions are getting worse. Tab. 7 confirms this statement, where it is clear that the worst and the best possible modulations are being used the most of the time which is unique comparing to other modulation intensities in remaining scenarios presented herein. Modem seems to be unlikely to change modulation to any between best and worst but rather stays in previously chosen state unless radical change in radio condition happens. As we can see on the right sides of both Fig. 5 and Fig. 6 , there was an area where signal strength returned to good values but modulation changed only for slight moment (see the middle part of the line along the street "3"). It is worth noting, that Fig. 6 shows modulation transitions illustratively, more detailed information is presented in Tab. 7. Also, what is interesting to note, is the fact that in the test with higher bitrate, a higher modulation (QAM-ctc-5/6) was encountered more often than in scenarios with lower bitrate traffic, where the more robust QPSK-ctc-1/2 modulation was used most of the time.

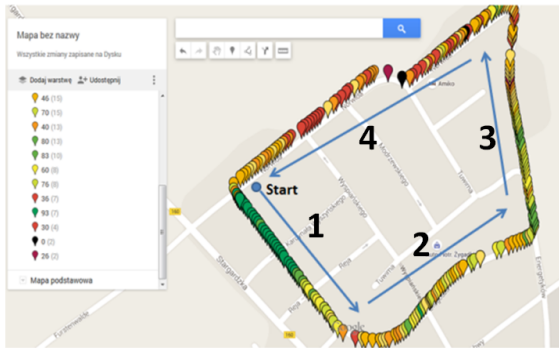Another interesting observation is a relatively low frequency of transitions between different modulations,
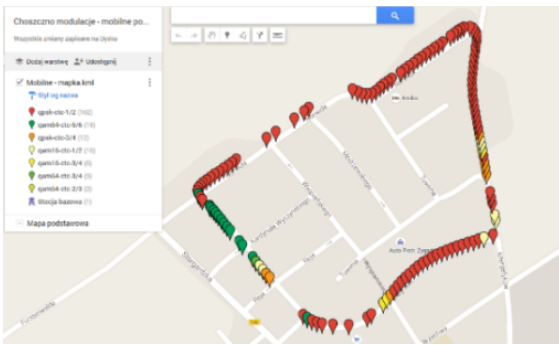
Fig. 5: Signal Quality

Fig. 6: Modulation changes

measurement, the best modulation possible QAM-ctc-5/6 was maintained nearly 35% of the time, even though for the most time, the network struggled to meet the expectations, due to bad signal quality. Figures (Fig. 8 - Fig. 10) show a summary of modulation changes and RSSI (Received Signal Strength Indication) statistics during one of mobile measurement laps. Numbers on the bottom of figures indicates in which part of streets those results were gathered (see Fig. 5). As we can see modulation changes are heavily dependent on radio conditions and seem to follow changes in RSSI/CINR. Please note that figures below seem to be very similar to each other. As for the downlink direction, Tab. 8 and Tab. 9 show the overall results of mobile tests. Clearly, both average delay and packet loss ratio values are significantly lower than in the uplink direction. What is interesting to note, is that other than the QPSK-ctc-1/2 modulation, the QAM16-ctc-1/2 was used for the longest period of time. Also similarly to uplink direction, transitions between different modulations occurred relatively rare.

Tab. 7: Modulation characteristics in mobile uplink tests

Measurement	qpsk-ctc-1/2	qpsk-ctc-3/4	qam16-ctc-1/2	qam16-ctc-3/4	qam64-ctc-2/3	qam64-ctc-3/4	qam64-ctc-5/6	Transitions
15 km/h 128 kb/s	65,53%	9,25%	4,00%	2,02%	0,00%	7,50%	10,46%	1,26%
15 km/h 1024 kb/s	39,31%	5,75%	14,06%	1,82%	0,67%	3,01%	34,75%	0,63%
30 km/h 128 kb/s	66,00%	4,11%	7,02%	2,85%	1,13%	0,40%	16,90%	1,59%
30 km/h 1024 kb/s	35,65%	12,72%	13,73%	4,32%	0,45%	1,79%	30,65%	0,68%

Analysis of delay behavior

To better analyze the causes of the increased delays and behavior of throughput we have performed similar mobility tests (i.e. with NLOS and mobility and rectangular path) as described above but in empty network (with only 1 client connected to BS and no other traffic beside it). We made sure that radio conditions are similar to the ones from figures Fig. 9 and Fig. 10.

especially given the fact, that the testing area was characterized by high variation of the signal quality. We have found that this observation is valid for almost every single test we have done. The intensity of modulation changes irrespectively to the nature of test (mobile, stationary) was at most 3% of time of test duration. Fig. 7 shows instantaneous throughput level measured for a single lap in the uplink direction with the car speed equal to 30km/h. In this test, we have put a constant bit rate equal to 1Mb/s. Interestingly, in that particular

Although the resulting speed (6 Km/h) and loss rates are less than 10% for all measurements, for single antenna case delay spikes reach up to 3,5 seconds and during low RSSI (less than 80dBm - ca. 25% of test duration).
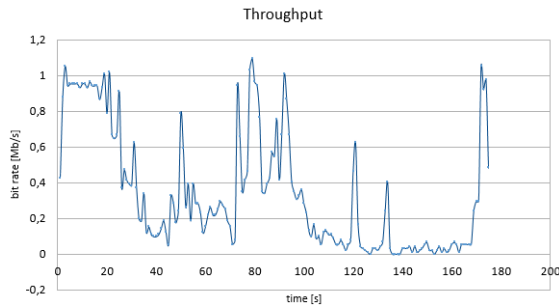
Fig. 7: Received throughput values during a single mobile test with the speed of 30km/h

Fig. 9: RSSI values during a single mobile test with the speed of 30km/h

Meaning that when terminal has entered NLOS area the average delay increased to average value of 170ms and 133ms for 128Kbps and 1024Kbps respectively (with standard deviation of 175 and equal for both single antenna cases). In order to further analyze observed behavior we have repeated these tests with MIMO-A enabled. It can be seen that there is significant decrease in average delay by ca.100ms on average (and standard deviation is just 4-7% of single antenna) with MIMO-A activated especially visible for the NLOS part of test.

This is inline with the expected behavior as the poor delay and throughput results inside NLOS area are due to CINR being close to the boundary between lowest modulations, which is also impacted by NLOS conditions, while MIMO-A is improving CINR.
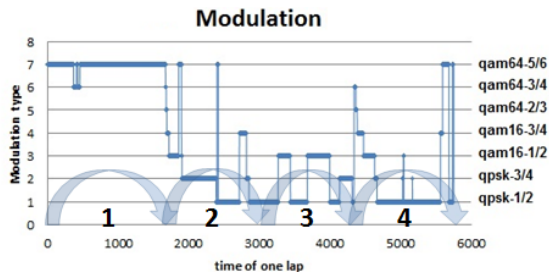

Fig. 10: CINR during a single mobile test with the speed of 30km/h

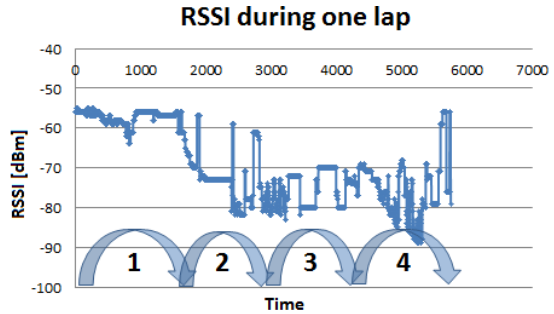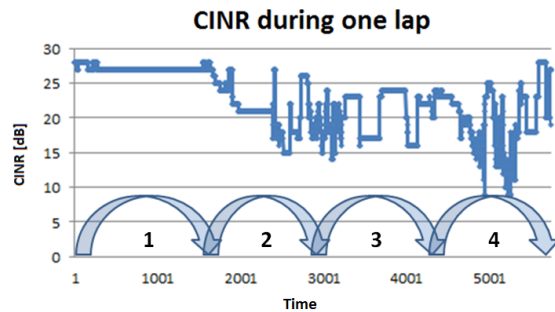Tab. 8: Overall delay results for the mobile downlink scenarios

Mobile Downlink	Avg Delay	Std Deviation	Packets received	Packets lost	Overall	Packets lost ratio
15 km/h 128 kb/s	20,09	5,56	3394	45	3439	1,3%
15 km/h 1024 kb/s	28,36	16,30	24816	592	25408	2,3%
30 km/h 128 kb/s	21,03	6,45	2040	40	2080	1,9%
30 km/h 1024 kb/s	32,53	23,33	324	2141	16429	2,0%

Fig. 8: Modulation transition scheme during a single mobile test with the speed of 30km/h

Tab. 9: Modulation characteristics in mobile downlink tests

Measurement	qpsk-ctc-1/2	qpsk-ctc-3/4	qam16-ctc-1/2	qam16-ctc-3/4	qam64-ctc-2/3	qam64-ctc-3/4	qam64-ctc-5/6	Transitions
15 km/h 128 kb/s	30,44%	4,28%	32,88%	11,18%	0,64%	0,56%	18,45%	1,57%
15 km/h 1024 kb/s	32,31%	16,49%	23,65%	7,42%	2,91%	5,64%	11,00%	0,59%
30 km/h 128 kb/s	33,88%	0,66%	35,53%	8,13%	6,20%	1,93%	11,61%	2,07%
30 km/h 1024 kb/s	36,04%	12,46%	28,58%	5,82%	2,77%	2,42%	11,55%	0,34%

It can also be observed that activating second antenna at

the CPE site significantly decreases both loss and standard deviation of the delay metric. The statistics of HARQ counters show that after entering the NLOS area number of HARQ retransmissions increases significantly. Number of retransmitted packets was 20% (for 128 Kbps, 1 antenna), 6% (for 1024 Kbps, 1 antenna), 3% (for 128 Kbps, 2 antennas) and 6% (for 1024 Kbps, 2 antennas).

Tab. 10: Summary of mobile tests with NLOS (the statistics are for the NLOS area only)

Utp Walk	Avg Delay	Std Deviation	Packets received	Packets lost	Overall	Packets lost ratio
128-Up-1A	167,97	175,78	1859	144	2003	7,2%
1024-Up-1A	133,58	175,73	15688	1868	17556	10,6%
128-Up-2A	63,20	8,93	2991	7	2998	0,2%
1024-Up-2A	32,93	13,27	16627	17	16644	0,1%

6 Conclusions and future work

The tests presented have clearly shown that uplink direction is not optimized for mobility in the commercial networks mostly due to lack of business motivation (cases) to do it. Especially it is clear that locations with poor signal coverage leads to high increase in uplink delays especially when the antenna is mobile and experiences NLOS. The results have shown that in locations with poor signal quality (i.e. below 40%) the height of mobile antenna and the mobility causes delay to rise to levels of 400-500ms. For mobile tests in the worst-case 92% of the RTT delay is attributed to uplink direction as the delay in downlink never exceeded 40ms. In addition the mobility changes the average level of delays/throughputs extensively. For the stationary tests delay in uplink hardly ever exceed 110ms in uplink (and 25ms in downlink). Additional tests we have performed have shown that after enabling MIMO in the uplink direction (without changes to ARQ/HARQ default settings) the IP performance metrics have significantly improved with NLOS conditions. With MIMO due to increase in signal quality (by ca. 10dB) the delays in mobile conditions has decreased to an acceptable value (ca.110ms) and throughput has been increased as well.

The MITSU project is trying to address such problems especially by introducing adaptable transcoder which can assure appropriate video adjustments for multiple cameras sharing the radio resources. As next step we are aiming at combining the cross-layer control of the BS resources with adaptability of transcoder via key control parameters (FPS, FOV, PPM).

Acknowledgment

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