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Trials of 60 GHz Radio for a Future 5G New Radio (NR) Solution for High Capacity CCTV Offload and Multimedia Transfer

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Abstract—This paper studies the radio interface performance of a 60 GHz radio in both indoor and outdoor conditions. The target is to assess its suitability for resolving emerging needs in the public transport, especially, in rail traffic, to transfer large amounts of data from vehicles to the stations and vice versa, during a short period of time. 60 GHz could also be ideal band for the wireless inter-carriage connection between the railcars. The related services and requirements are defined in the 5G specification Mobile Communication System for Railways - TS22.289. 60 GHz band is also included in the 5G standard as an unlicensed band.

Index Terms—Field Trials and test results, Traffic and performance monitoring

I. INTRODUCTION

The CCTV systems in public transport systems, such as in trains, trams and metros are becoming more and more popular. Typically such video security systems consist of multiple cameras with minimum resolution of 1080p. The cameras are recording video feeds 24/7, which are stored locally into the video recorders located in the trains and/or into internal memory of the cameras. The regulations in different countries [1], [2], [3], [4], have set retention time requirements and requirements for the recordings, which can be up to 31 days or even more. Furthermore, the retention time for the storage time of the recordings stored in the vehicle storage, e.g., in the United States is seven days, after which the recordings need to be transferred into the ground storage. The transfer of video recordings from vehicles to the ground system is challenging, since the vehicles in the public transport systems are almost constantly on the move and hence the only possibility to transfer video storages from train to ground is when the vehicle stops at stop or station. Since the amount of video recordings is excessive, very high capacity wireless link is required, in order that sufficient amount of video storage can be transferred from train to ground and overflow of storage space in train can be avoided. Based on the estimation calculations represented in [5] and in [6], the transfer of CCTV archives from train to ground, also known as wireless offload [7] or CCTV offload [5], [6], requires minimum of one Gbps throughput, in order that the CCTV archives in the train can be sufficiently transferred to the ground. The transfer of the CCTV archives, i.e. CCTV offload, is done every time when the train stops at a station. The 3GPP also defines services and requirements in [6] for the use cases where minimum of one Gbps throughput is required for the transfer of large data archives, e.g. multimedia from ground

to train and when the wireless connection between the two railcars needs a minimum of one Gbps throughput. In order to meet the throughput requirement for the given services and use cases defined in [5] and [6], the paper investigates the performance of unlicensed 60 GHz 5G band for the task. The paper studies the performance of a commercial 60 GHz radio in indoor and outdoor environments, and also takes into account different environmental effects, such as weather, to evaluate the suitability of the high frequency link. A high level description of the use cases and service scenarios is illustrated in Fig. 1.



Fig. 1. Considered use cases of the high data rate link. Above: Transmissions from ground to train and vice versa. Below: Inter-carriage transmission.

II. CAPACITY CALCULATIONS

The capacity calculations represented in [5] and in [6] are based on example scenario where the following is assumed:

- The retention time for the recordings in the onboard system is seven days
- The minimum retention time for the CCTV recordings in the ground system is 31 days

- Video storages are transferred from train to ground, only when the train approaches stations in order to stop and at the depot.

The configuration and example calculation of the video storage need during 31 day period is depicted in Fig. 2. An example calculation is done for an actual train route in Finland between Helsinki and Kemijärvi, based on the CCTV configuration depicted in Fig. 2 and details of the train route are provided in Table I.

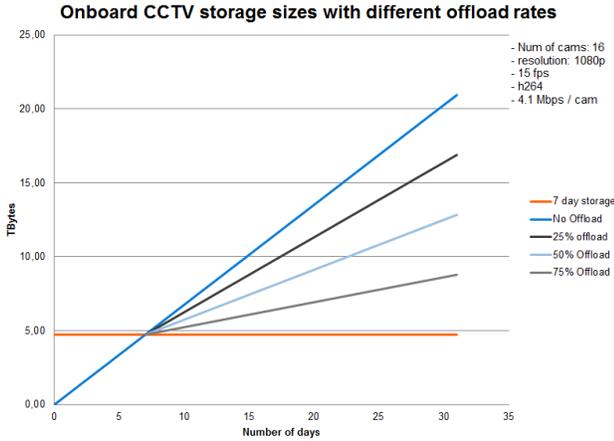


Fig. 2. The configuration and example calculation of the video storage need during 31 day period.

TABLE I

THE PARAMETERS OF THE CCTV OFFLOAD CALCULATION FOR THE TRAIN ROUTE BETWEEN HELSINKI AND KEMIJÄRVI.

Station	Arrives	Departs	Stop	Betw. stn
Helsinki		18:52		
Pasila	18:57	19:00	0:03	0:08
Tikkurila	19:41	19:44	0:03	0:44
Riihimäki	20:19	20:22	0:03	0:38
Hämeenlinna	20:46	20:48	0:02	0:26
Tampere	21:38	22:11	0:33	1:23
Parkano	23:03	23:06	0:03	0:55
Seinäjoki	0:08	0:10	0:02	1:04
Kokkola	1:37	1:39	0:02	1:29
Ylivieska	3:10	3:12	0:02	1:33
Oulu	4:42	5:00	0:18	1:48
Kemi	6:08	6:12	0:04	1:12
Rovaniemi	7:47	7:55	0:08	1:43
Misi	8:31	8:32	0:01	0:37
Kemijärvi	9:00	9:05	0:05	0:33

The CCTV offload results were calculated based on three different uplink speeds; 450 Mbps, 750 Mbps and 1000 Mbps, respectively. In the calculations, depicted in Fig. 3 - 5, the following three variables were inspected;

- *Data In*, i.e., how much video data is stored into the storage in the train during transit from station to another.
- *Data output capacity*, i.e., how much the system is able to transfer data from train to ground during the stop at the station.

- *Left*, i.e., how much there is left video data in the train storage when the train outbounds into another station.

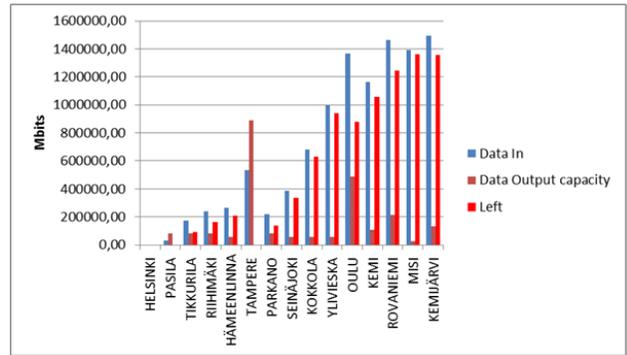


Fig. 3. Inspection of CCTV offload variables with uplink speed of 450 Mbps.

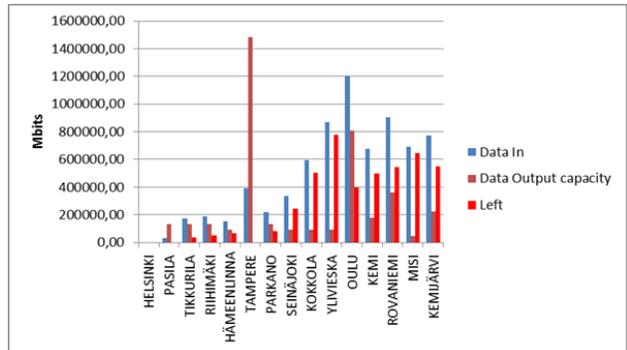


Fig. 4. Inspection of CCTV offload variables with uplink speed of 750 Mbps.

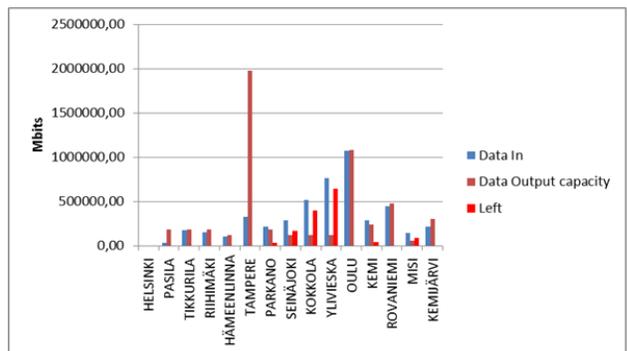


Fig. 5. Inspection of CCTV offload variables with uplink speed of 1000 Mbps.

As the inspection of CCTV offload variables in Fig. 3-5 shows, the minimum uplink speed required for the CCTV offload based on this example calculation is 1 Gbps.

III. OBJECTIVES

The objective is to study the utilization of a 60 GHz radio for the high capacity (i.e. min. one Gbps) CCTV offload from train to ground, uploading of multimedia databases

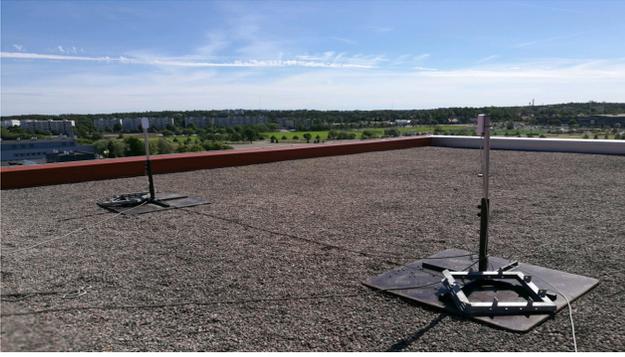


Fig. 6. Outdoor trial setup

from ground to train and for the high capacity inter-carriage link between the railcars. The focus of this study is in the performance of radio interface of the link which is the essential and most critical part and contributes mostly to the overall data throughput and reliability. The preferred link distance stemming from the use case is considered to be 5 to 20 meters. The reliability and data throughput have been studied with different environmental effects such as:

- Distance between the devices
- Shadowing objects: e.g. people, steel plate
- Tracking speed, mobility
- Rain, icing and humidity

IV. SETUP

Commercially available Mikrotik Wireless Wire devices were used in the study. The device is based on 802.11ad standard operating on the 60 GHz frequency band. Mikrotik link utilizes Qualcomm components with phased array 60-degree beamforming antenna with 32 antenna elements. Dynamic beamforming creates very narrow beams towards users, and thus concentrates the power efficiently towards the other end of the link in line of sight (LOS) conditions. In many cases also NLOS conditions can result in high data speed connections due to steerable multiple antennas via reflections. The link utilizes single carrier technology and bandwidth is up to 2 GHz, allowing multigigabit transmission bitrates between the devices. The maximum raw bitrate is reported to be up to 6756 Mbps and 4,7 Gbps is supported at ranges up to 10 meters and 2 Gbps up to 40 meters according to [8]. Studies on indoor performance of 802.11ad are presented for example in [9].

During the measurements automatic frequency selection was used which support center frequencies 58320, 60480, 62640 and 64800 MHz. Achieved bitrate depends on the received signal level which controls the used modulation and coding schemes (mcs). According to the standard twelve mcs values are defined by numbers from 1 to 12.

Iperf-application was used to measure the actual throughput of the system in different conditions. The installation of the outdoor setup is shown in Fig. 6.

V. TRIALS

The experiments studied the performance of the link with different weather conditions and link distances in outdoor and indoor environments. Based on the rail traffic use cases, 5 meter distance is considered representative for the outdoor measurements (the distance from the train to the infrastructure at the station). Further, the supported link distances were trialed up to 70 meters. The link selects the channel automatically based on interference and noise level. During the test period it was noticed that always frequency 58320 MHz was in use. Radio frequency parameters and signal level measurements are presented next.

A. Transmitter power

Exact transmitter (TX) power or EIRP is not given in the technical data released by the manufacturer. TX power was fixed in the beginning of trials but after some software updates the power was selectable by operator and has levels from 1 to 15 in rising order. The measurement results revealed that the power control dynamic range is quite narrow and for example with maximum power level 15 in the distance of 5 m the received signal strength (RSSI) value was -50 dBm and -55 dBm with level 4. Thus the power difference between steps is in the order of 0,5 dB if the control curve is linear between level 4 and 15. From the measured maximum received power -50 dBm it is possible to estimate the TX EIRP using free space loss (FSL) equation.

$$FSL[dB] = 32.4 + 20\log(f) + 20\log(d), \quad (1)$$

where f is frequency in MHz and d is distance in km. FSL is 81,7 dB when frequency is 58320 MHz and distance 5 m. Received power plus FSL gives EIRP 31,7 dBm which is little over 1 W. Maximum RF output power in outdoor use is 40 dBm (EIRP) in ETSI standard EN 302 567/10/.

B. Long term signal level

One example measurement result of the signal level variation during 24 hours in summer time and in clear weather conditions is illustrated in Fig. 7. The distance between the station and client is 5 m. The station RSSI is most of the time between -50 dBm and -47 dBm and the client between -51 dBm and -48 dBm.

C. Rain and snow attenuation

Measurements during different raining and snowing conditions proved that attenuation is negligible when distance is 5 m. Fig. 8 illustrates the effect of rain on the RSSI during 6 h measurement period when the highest rain intensity was 30 mm/h . RSSI is -55 dBm and very stable during the entire period.

D. Physical bitrate, modulation and coding schemes and fading margin

Bitrate depends on used modulation and coding. The link selects the modulation and coding scheme (mcs) depending on the signal strength, channel conditions, noise and interference.

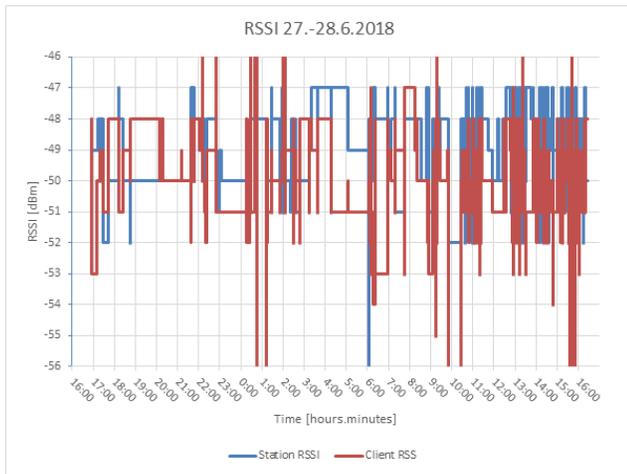


Fig. 7. Signal strength during 24-hour measurement.

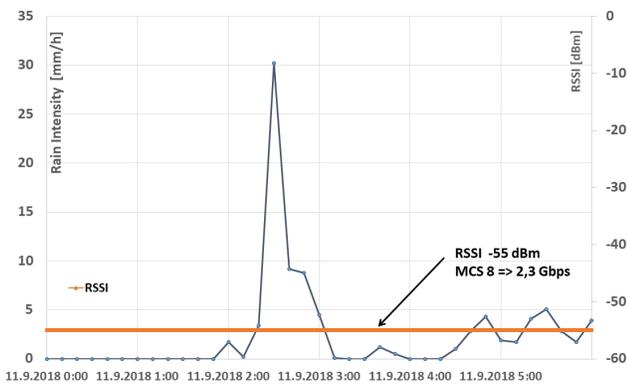


Fig. 8. Rain intensity and received signal strength during 11.9.2018.

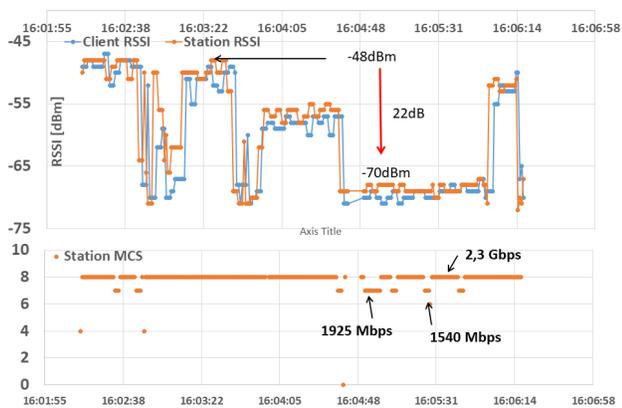


Fig. 9. Received signal strength and modulation coding scheme.

Fig. 9 illustrates the signal levels, mcs and physical bitrates of one measurement where signal path attenuation is changed. In this measurement maximum transmitted power was used which results maximum -48 dBm received power. Signal was then attenuated until -70 dBm RSSI was measured and mcs is decreased to value 6 supporting 1540 Mbps bitrate and the

TABLE II
MCS VALUES AND BITRATES OBSERVED DURING TRIALS.

mcs	1	2	3	4	6	7	8
PHY (Mbps)	385	770	962	1155	1540	1925	2300
TB (Mbps)		574		831		846	846
aTB (Mbps)		504		632		733	707

TABLE III
LINK DISTANCE AND CORRESPONDING FRESNEL ZONE MAXIMUM RADIUS.

Distance (m)	5	10	20	40	80
Radius (cm)	8	11	16	22	32

link thus has 22 dB fading tolerance. The maximum bitrate of 2.3 Gbps is measured when RSSI is -68 dBm and mcs is 8. Mcs value 7 was measured with RSSI -69 dBm thus one dB change in signal level cause the change in mcs and bitrate. Signal level -71 dBm drops the mcs to value 4 and 1155 Mbps bitrate thus 3 dB change in signal level decreases the bitrate from 2.3 Gbps to 1155 Mbps which was defined as minimum bitrate in this application. During the trials it was observed that the link dynamically used mcs 1-8 except 5 which was never found in the results. Highest mcs measured was 8 which supports 2.3 Gbps. Tsunami UDP Protocol for fast file transfer was used to verify that the physical bitrates are in line with the real data throughput of the link. During the entire trial period measured mcs value, physical bitrate (PHY), data throughput (TB) and application data throughput (aTB) are presented in Table II. The standard supports, when single carrier technique is used mcs values up to 12 and bitrate up to 4.6 Gbps but the mcs 9 to 12 were never used by the link during these trials.

E. Human body attenuation

When conducting measurements to investigate effects of different objects and material on the link direct path it is advantageous to know the size of Fresnel zone. Fresnel first ellipsoid is the surface around the direct radiowave ray which has half a wavelength longer path than the direct line between the transmitter and receiver. Theoretical free space loss calculations are valid if the first Fresnel ellipsoid is free of obstacles and if not then additional attenuation factor need to be added. Attenuation depends on shadowing area, obstacle material, size, shape etc. Maximum ellipsoid radius is in the middle of the link distance and is a function of frequency and link total distance. Ellipsoid maximum radius is calculated in different practical distances and presented in Table III. If for example the link is mounted on the railway carriage on the height of 2.5 m above level where people are moving then Fresnel zone would be free of human obstacles even in 80 m link distance when the zone radius is 32 cm. Hence, ellipsoid lower boundary is in the height of 2.18 cm and safely above people.

LOS Measurement example of the effect of human body on 60 GHz radio link is shown in Fig. 10. Transmitter power

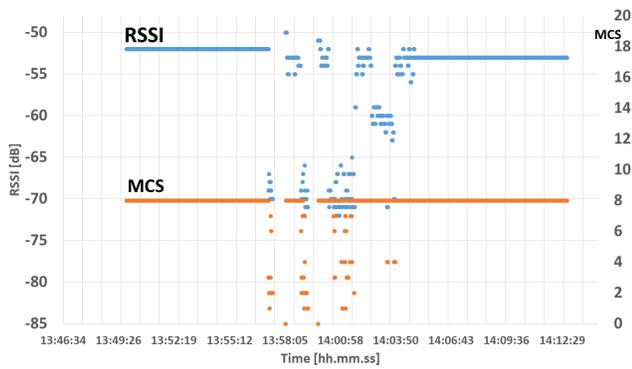


Fig. 10. Human hand and body effects on signal strength and modulation coding scheme

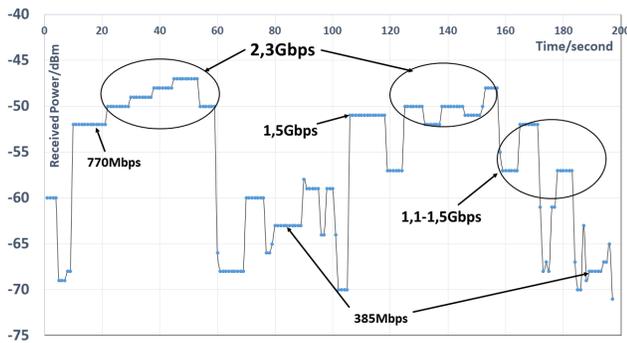


Fig. 11. Signal strength and bitrate variations when client is moved and station is fixed installed.

setting value 4 was used to attenuate the effects of nearby reflections. This TX power gives -54 - 55 dBm RX power level. First, hand was held in the distance of 2 cm from the Station link side (13:57) one minute which caused RF signal attenuation by 14-18 dB. When hand was removed the link recovered in seconds. The Client side had same effect (13:59). In both cases the RSSI value decreased to -67 - 78 dBm and mcs dropped to zero and the link cut off. Tall male body (190 cm, 14:01) in the middle (appr. 2.5 m) of the link decreased the RSSI to -67 .. 73 dBm and mcs to 2. Shorter male body (180 cm, 14:03) decreases the RSSI to -61 .. 65 dBm.

F. Mobile client

Moving the client with speed of 3-5 m/s into the beam steering sector was tested to simulate a situation where client is mounted in a train which is slowly approaching the railway station. Signal strength variation and corresponding bitrates are illustrated in Fig. 11. The link RSSI reacts very fast when the client moves inside or outside the beam steering sector which happens in the time axes point 10 s and 60 s in Fig. 11. When the signal has reached sufficient level e.g. -52 dBm in point 10 s then the RSSI takes several seconds to react.

G. Ice attenuation

The link was sprayed with cold water to build ice on the link case surface in winter weather. When the link is powered



Fig. 12. Link front part covered with ice in winter time.

and transmission mode the rf signal melts a hole on the ice above the internal antenna which is visible in the upper left part of the photograph in Fig. 12. Beam steering was fixed to center position to avoid other paths. This 1-2 mm thick ice condition had no effects on the link performance and the signal strength was -49 - 50 dBm. When 15 mm thick ice layer was in the client side the signal level decreased to -52 dBm thus attenuation is 2 dB. Then 10 mm thick ice was added to the station side. This had no noticeable additional attenuation to previous measurement. Iperf result was 800 Mbps bitrate and 0.02% packet loss. 10 mm more ice layer and snow was added on the client side which is shown in the right side photo of fig. 12. This total of 35-40 mm of ice and snow decreased the signal level to -66 - 67 dBm which can still maintain the highest 2.3 Gbps physical bitrate for the client but station side decreased to 962 Mbps and mcs value 3. Iperf speed was 600 Mbps and packet loss 0,029%. It was also noticed that if the distance to the ice layer is longer than 10 cm then the link will find other paths if reflective material is in the vicinity and beamforming is allowed and link signal level is higher than in the direct path resulting higher bitrates via the reflection paths.

Main findings of the experiments are:

- Signal strength variation is roughly ± 2 dB and bitrate between 1-2 Gbps in line-of-sight conditions and link distance range of 5 to 70 m.
- Radio interface fading margin is in order of 20 dB with minimum physical bitrate requirement of 1 Gbps and link distance 5 m.
- Throughput of hundreds of Mbps achieved when in no line of sight conditions, but reflections are available.
- Human body in the direct path attenuates 15-25 dB depending on the size and position and leads to unacceptable low throughput or even cut off the link connection. However reflection paths could exist depending on environment.
- Rain and snow has negligible attenuation in short distances
- Ice on the surface of the link enclosure or immediate

vicinity attenuates but the ice layer must be several cm thick to impose notable effect on the link quality.

- Link acquisition time is less than 1 second when the client and station move inside the beam steering sector (60 deg).

VI. CONCLUSIONS

The trials indicate that 60 GHz radios can provide a high-speed link in short distance outdoor applications that is highly tolerant for attenuation and different arctic weather conditions in the measured scenarios of this paper. High throughput can be achieved even with distances up to 70 meters. The connection between the radio units is formed quickly once the units are in acquisition sector of the beamforming antennas. Further, the beamforming allows several device pairs to be used in parallel to multiply the throughput. According to this study, the 60 GHz radio can fulfill the requirements for connecting the train to infrastructure at the station while offloading CCTV data and for the intercarriage connectivity.

ACKNOWLEDGMENT

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