

5G NR Testbed 3.5 GHz Coverage Results

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Abstract – 5G New Radio (NR) has attracted a large amount of interest with its foreseen improvement of user experience and capacity. To become a commercial success coverage is also an important consideration. The sub-6 bands are expected to provide good coverage. One such useful band is 3.5 GHz. In this paper the coverage of 3.5 GHz is studied by means of a full-scale trial with a NR testbed. With beamforming the increased propagation losses at 3.5 GHz compared to 2.1 GHz can be compensated and the coverage was demonstrated to be on par with 2.1 GHz LTE fixed antenna coverage both outdoor and indoor.

Keywords – 5G NR, sub-6, beamforming, testbed

I. INTRODUCTION

The fifth generation (5G) New Radio (NR) targets improved capacity, user experience and coverage, [1]. For coverage there are explicit link budget requirements but also scenario dependent site density performance requirements. The former is expressed as coupling loss in dB, while the latter is expressed in distance and is frequency dependent. Lower frequency bands have a distance coverage advantage from the larger effective receiver antenna area and better propagation conditions. The effective antenna area has the basic frequency dependent property proportional to the squared wavelength. The sub-6 (below 6 GHz) bands are therefore attractive for coverage reasons. The 3.5 GHz band is of interest with expected good coverage with potentially relatively large bandwidth available.

5G NR includes good support for massive MIMO. This enables beamforming which improves distance measured coverage. In this paper coverage results are presented from measurements with a 3.5 GHz NR test-bed with massive MIMO beamforming. An assessment of relative coverage compared to a fixed LTE antenna on the 2.1 GHz band is also considered. The impact on propagation properties by carrier frequency has previously been studied by e.g. [4] and [5].

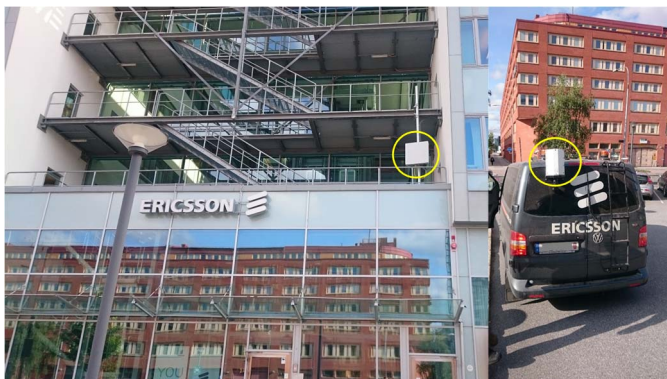


Figure 1. Testbed transmission/reception point (left) and van with terminal (right).

The rest of the paper is organized as follows. Section II gives an overview of the testbed used, deployment and field-trial environments. Section III presents the results. Finally, the conclusions are drawn in Section IV.

II. TESTBED AND TEST ENVIRONMENT

A. Testbed details

The 5G testbed radio interface has the same main structure as 3GPP NR: time division duplex (TDD) and orthogonal frequency division multiplexing (OFDM). The testbed supports up to 256 QAM modulation in the downlink (DL) and up to 64 QAM in the uplink (UL). In this trial the deployed TDD configuration is set for maximum DL throughput with a DL:UL ratio of 48:2. The system design, including baseband, terminal and transmission/reception point (TRP) is the same as for the mm-Wave testbeds in [2] (15 GHz) and in [3] (28 GHz).

The bandwidth is 80 MHz, centered at 3.5 GHz. The terminal has 200 mW transmit power and is mounted in a van with an external omnidirectional antenna, see Fig. 1.

The TRP is a micro cell prototype with 5 W transmit power and a massive MIMO solution with support for up to 16-layer (in the presented tests up to four layers are used) spatial multiplexing with two dual polarized MIMO streams. The antenna array has 128 cross-polarized antennas, organized as eight rows and 16 columns. Two vertical antennas are combined to a sub-

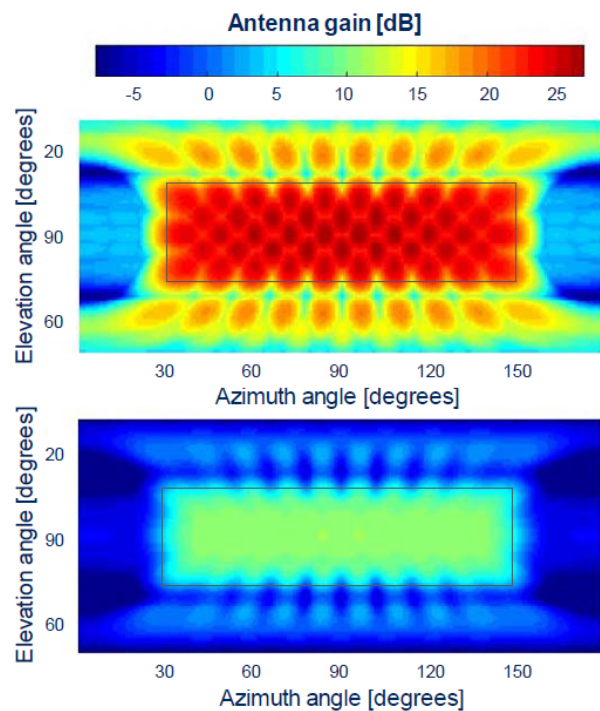


Figure 2. Beam grid of the TRP (top) and, for comparison, a reference wide beam with the same angular coverage (bottom).

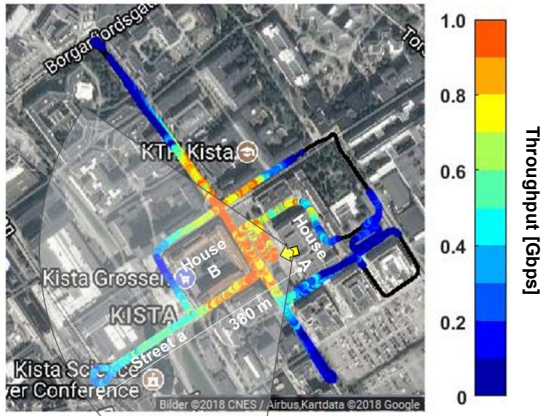


Figure 3. Dense urban DL throughput coverage on 80 MHz bandwidth.

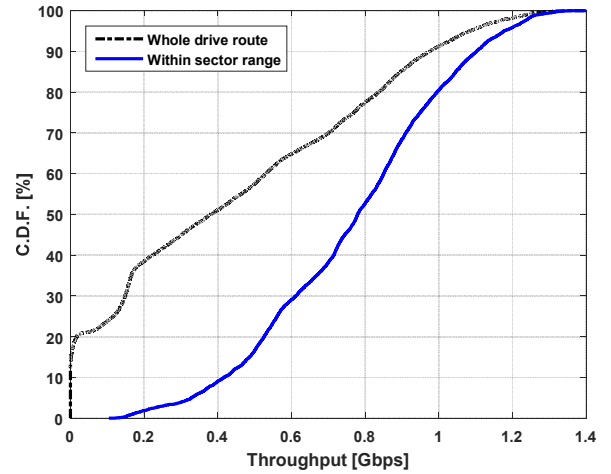


Figure 4. Dense urban DL throughput distribution.

array, so that one vertical (V) polarization input is fed to two V polarized adjacent vertically placed antennas, and one horizontal (H) polarization input is fed to the two H polarized antennas. Hence there are 64 dual polarized sub-arrays, four rows and 16 columns. There are 128 radio chains, i.e. 128 different power amplifiers where 64 are used for one polarization and 64 for the other. Half of the baseband layers will be sent out on the V polarization and the other half on the H polarization.

The TRP uses digital beamforming, i.e. beamforming in the frequency domain, with a grid-of-beam (GoB) solution with 48 different candidate beams. These are arranged in a grid of five rows with either nine or ten beams each resulting in a grid coverage of approximately ± 60 deg. in azimuth and ± 15 deg. in elevation, see Fig. 2 (top).

For each of the 48 beam candidates, the signal quality is assessed by measuring the signal strength of mobility reference signals (MRS) transmitted in subframes 0 and 25. The MRSs are then used to establish subframe synchronization and to identify which DL beams to use. All 48 beams are cycled through for both polarizations in 20 ms and measurement reports are being transmitted every 5 ms. Further details on the implemented beam acquisition process are given in [2, 3, 6].

TABLE 1. MAIN SYSTEM PARAMETERS.

Key parameter	System	
Carrier frequency	3.5 GHz	
Bandwidth	80 MHz (3.460 – 3.540 GHz), 1 carrier	
Radio access	OFDM	
Duplex	TDD	
Maximum modulation	256 QAM in DL, 64 QAM in UL	
Subcarrier spacing	75 kHz	
Subframe length	0.2 ms	
Symbol duration	13.3 μ s + CP 0.94 μ s	
Duplex scheme	TDD (DL:UL=48:2)	
	TRP	Terminal
Antenna gain	27 dBi	5 dBi
Total output power	5 W	200 mW
EIRP	64 dBm	24 dBm/direction
Half-power beamwidth (HPBW)	6 deg. in azimuth 12 deg. in elevation	90 deg. in azimuth and elevation per antenna element

Key performance indicators such as DL throughput and signal strength (i.e. MRS received power, MRSRP) are being logged every 100 ms while geographical data for the terminal is logged once every second. The considered DL throughput is layer 1 DL throughput originating from the transmission of full buffer dummy data. Main system parameters are summarized in Table 1.

B. Network deployment

The TRP is deployed in two different environments; one micro cell dense urban area (two locations) and one open line-of-sight (LoS) area (one location). In the first location in the dense urban area, the TRP is mounted at 8 m height on the outside wall (see Fig. 1) on House A (yellow arrow in Fig. 3) facing a square with mainly 6-10 floor buildings in the surrounding area. In the second location, the TRP is located on the roof-top of an office building at approximately 20 m height. Although the environment is similar to the previous one, this gives the deployment a characteristic of a macro deployment and in this case, is used for assessing indoor coverage. The second location and direction of the TRP is indicated in Fig 12 with a yellow arrow.

In the open area deployment, the TRP is mounted on a mast at 6 m height on top of a small hill with LoS along a road with very few surrounding buildings, see Fig. 7 (yellow arrow gives the location and direction of the TRP).

III. RESULTS

A. Dense urban coverage

The coverage and DL throughput in the dense urban deployment are shown in Fig. 3. Black markers indicate measured streets without coverage. The coverage is very good along the streets in the area. In the TRP bore sight direction within the horizontal beam grid range of ± 60 degrees marked with a sector in Fig. 3, the throughput is high. There is also significant throughput coverage outside the beam grid even behind the building House A where the TRP is mounted. This is due to reflections from buildings in front of the TRP. There is also coverage all around the 100 m wide seven floor bricked building block House B in front of the TRP (also seen in Fig. 1).

Fig. 4 shows the Cumulative distribution functions (C.D.F.) of the DL throughput for the whole drive route (black dash-dot) with the part located within sector coverage (blue). Around 80%

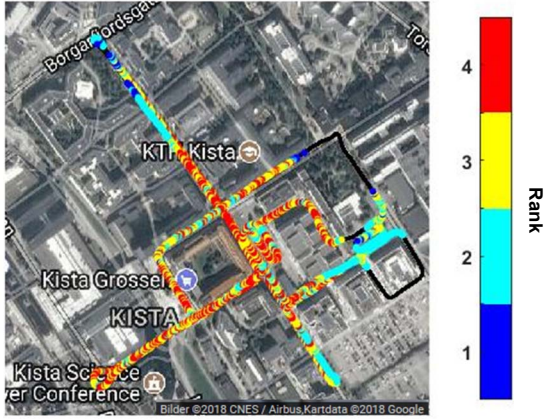


Figure 5. DL transmission rank along the drive route.

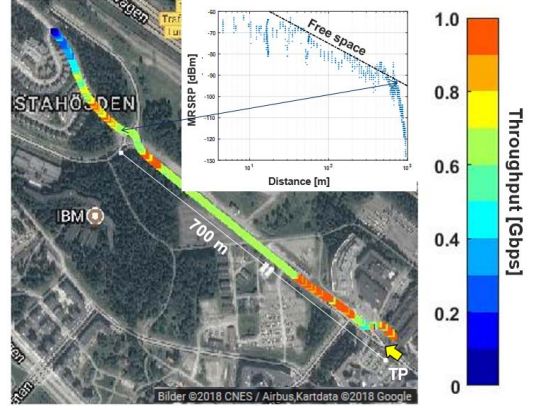


Figure 7. Long range coverage.

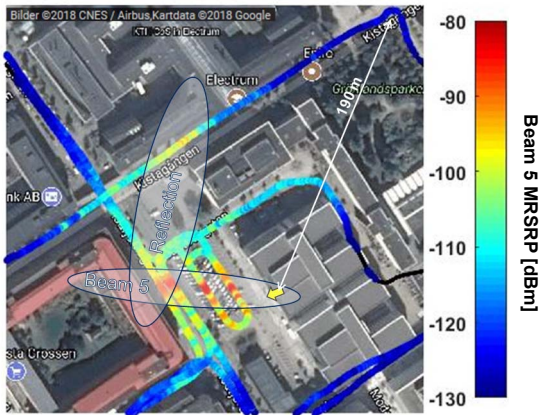


Figure 6. Beam 5 coverage.

of the drive route is covered supporting connectivity and downlink throughput. In the intended and expected coverage area sector of such a micro cell deployment the throughput is high, in LoS on the square in front of the TRP and nearby streets the DL throughput is between 700 Mbps and 1200 Mbps, and in non-LoS 200 Mbps or more is supported. This is also the case all the way up to 380 m distance along the non-LoS Street *a*, see Fig. 3. This demonstrates very impressive micro coverage ranges. As a comparison, in [1] the dense urban deployment scenario has a macro site distance of 200 m and there are three micro/macro sites. Spatial multiplexing and MIMO high rank contributes to the high throughput. In the measured area the used DL transmission rank is distributed as follows: rank 1: 2%; rank 2: 25%; rank 3: 35%; rank 4: 38%, see Fig. 5. The relatively high abundance of rank 3 and 4 indicates a reflective environment with multipath transmission.

To further illustrate the impact of reflections in the considered dense urban environment, the coverage of one specific beam – beam 5 – is shown in Fig. 6. The direction of the beam is clearly visible and marked in the figure. The increased signal strength in one part of the topmost street along the drive route (“Kistagången”) indicates the presence of a strong reflection, as marked in the figure. In this case it is the red-brown bricked building in the lower left corner of Fig 6 (House B in Fig. 3) that

is the reflector. It is also interesting to notice that beam 5 provides coverage in non-LoS behind the TRP as far away as 190 m.

B. Open area coverage

The coverage and throughput along the road in the open area environment are shown in Fig. 7. Also, the signal strength as a function of distance is presented. Up to 700 m there is LoS and the propagation loss is only the free space loss. This results in support for 700 Mbps up to 700 m distance.

Non-LoS makes the throughput decrease for the part of the drive route furthest away from the TRP sharper than the expected gradual free space decrease. Nevertheless, in non-LoS 100 Mbps is achieved at nearly 1 km distance.

C. Beamforming gain

An important reason for the good coverage is the massive MIMO antenna at the TRP enabling beamforming. To assess the beamforming gain, the measured signal strength of the strongest beam is compared with the signal strength that can be expected by a wide beam reference antenna. Such a reference antenna is here modelled as the sum of all beams with power equally distributed on all 48 beams, see Fig. 2 (bottom) for the corresponding sector antenna gain pattern. The beamforming gain is here calculated as [6]:

$$gain_{TB} = \frac{\max(mrsrp_{bix})}{\sum_{bix=1}^{48} mrsrp_{bix}/48} \quad (1)$$

where $mrsrp_{bix}$ is the linear measured MRSRP for beam index bix .

In Fig. 8 the beamforming gain in the first considered dense urban area is plotted. C.D.F. comparing the gain for the whole drive route (black dash-dot) with the part located within sector coverage (blue) are given in Fig. 9. Within the sector range, the gain is most often 11 dB or more, with peaks above 15 dB.

This gain can compensate for the additional losses at 3.5 GHz compared to a corresponding 2.1 GHz LTE deployment. The additional loss from a smaller effective receiver antenna area is 4.4 dB (i.e. $3.5^2/2.1^2$) which is 6.6 dB less than the beamforming gain, indicating better outdoor coverage with beamformed NR on 3.5 GHz than fixed antenna LTE on 2.1 GHz. The additional outdoor to indoor loss at 3.5 GHz is according to [5] 1-3 dB so also indoor loss with a beamformed NR micro deployment looks promising.

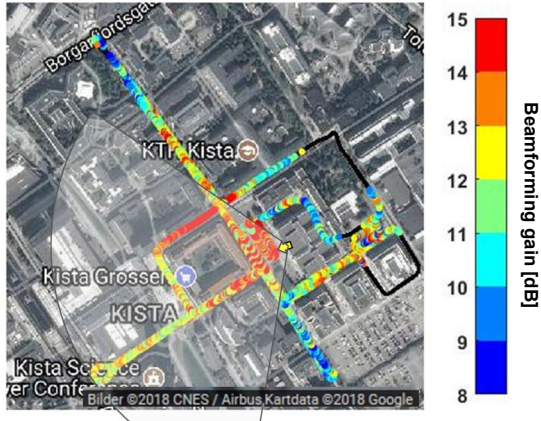


Figure 8. Beamforming gain.

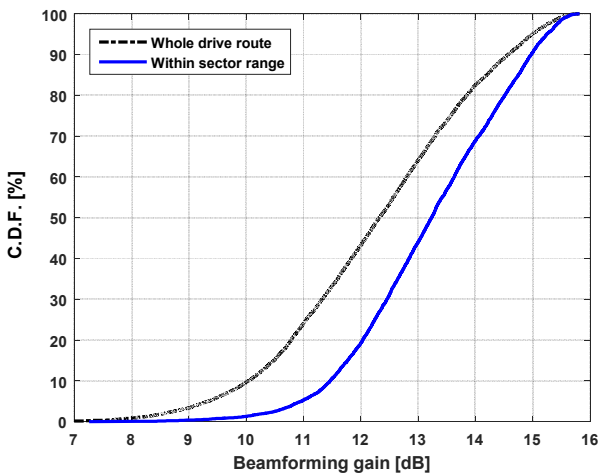


Figure 9. Beamforming gain distribution.

Table 2 summarizes a comparison of link budget and coverage for 3.5 GHz and 2.1 GHz. In the comparison the additional loss at 3.5 GHz compared to at 2.1 GHz is 5.1 dB outdoor, 7.1 dB indoor in an old building and 10.1 dB indoor in a new building. Assuming a beamforming gain of 11 dB for a beamformed implementation at 3.5 GHz, this gives an outdoor coverage advantage of 5.9 dB compared to a non-beamformed implementation at 2.1 GHz. For indoor, there is still an advantage for both the modelled old building (3.9 dB) and for the modelled new building (0.9 dB). Clearly, beamforming has the potential to overcome the additional frequency dependent losses at 3.5 GHz compared to 2.1 GHz, to be on par or be better than existing 2.1 GHz deployments in terms of coverage.

D. Predicted indoor coverage

The testbed maintains Mbps DL throughput down to around -130 dBm signal strength. Both DL and UL connection can be achieved at that level. With this defined as coverage limit the indoor coverage range is assessed for the buildings along the streets in the dense urban environment. The predicted covered distance into the buildings are the remaining margin between the signal strength on the street and -130 dBm. The used indoor propagation assumptions are as in Table 2 from [5]; outdoor to indoor loss 8 dB modelling old buildings and 0.6 dB/m in building loss. The predicted coverage range into the buildings on the side of the streets are shown in Fig. 10 (old building) and Fig. 11

TABLE 2. COMPARISON BETWEEN 3.5 GHz AND 2.1 GHz IN TERMS OF LINK BUDGET (TOP PART) AND COVERAGE (BOTTOM PART).

Link budget difference [dB] 3.5 GHz vs 2.1 GHz	
Receiver antenna area	-4.4
Receiver noise, assuming same bandwidth	0
Transmit power spectrum density, assuming same bandwidth	0
Outdoor propagation loss [4]	-0.7
Outdoor difference	-5.1
Outer wall loss old building [5]	-1.0
Indoor loss 20 m [5]	-1.0
Indoor difference old building	-7.1
Additional loss new building [5]	-3.0
Indoor difference new building	-10.1
Coverage difference [dB] beamformed 3.5 GHz vs non-beamformed 2.1 GHz	
Beamforming gain test-bed GoB	11.0
Outdoor link budget difference	-5.1
Outdoor coverage difference (= 11.0 - 5.1)	5.9
Indoor old building link budget difference	-7.1
Indoor coverage difference old building (= 11.0 - 7.1)	3.9
Indoor new building link budget difference	-10.1
Indoor coverage difference new building (= 11.0 - 10.1)	0.9

(new building). The indoor coverage looks very good for the old building type. Around the square and in LoS full coverage can be expected in the buildings. The coverage range along most of the streets within the beam grid range is 20 m or more into the buildings. One exception is behind the House B block where indoor coverage is less than 10 m into the building in one corner. Note that this is assuming old buildings and old windows. For new buildings with energy saving glasses, such as house A and other buildings in the area, the outdoor to indoor loss is expected to be around 22 dB [5] and coverage may be poor further away from the TRP. This is also challenging for LTE at 2.1 GHz and many of the buildings in the area are equipped with dedicated indoor solutions for that reason. Nevertheless, near the TRP the

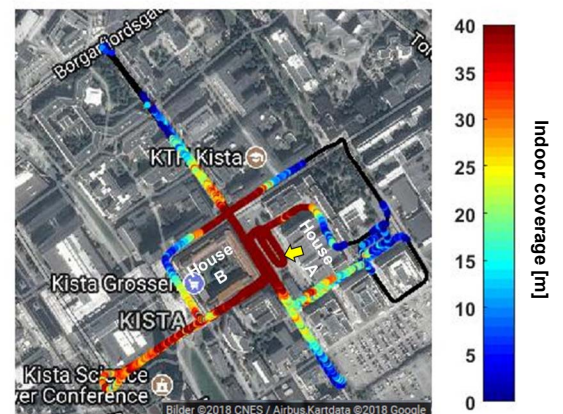


Figure 10. Predicted indoor coverage range for old building.

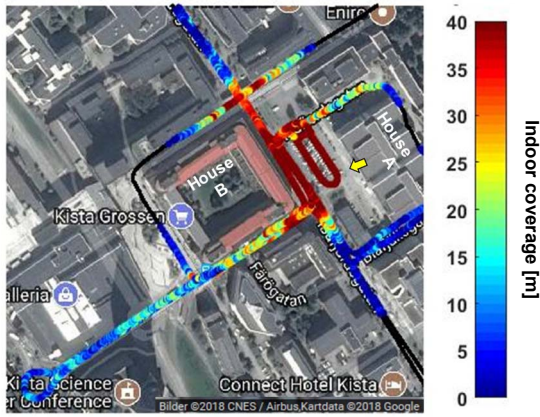


Figure 11. Predicted indoor coverage range for new building.

expected modern building indoor coverage range is often 20 m or more, see Fig. 11.

E. Measured indoor coverage

Fig. 12 depicts measured indoor coverage on the top floor (floor six) of the office building House A located across the street from the building where the TRP is located on roof-top. The measured building is modern with coated energy saving windows. The penetration loss of the windows was measured to around 21 dB, which is close to the expected 22 dB [5]. Note that the considered building is located outside of the intended beam coverage (the rectangular area in Fig 2 (top)) which results in lower signal strength. Now the selected beams are in the lower left part of the beam grid, just outside of the coverage area. Nevertheless, the indoor coverage is fairly good. The length of the straight corridor that goes up to the left corner in the figure is around 40 m, and along this path coverage is maintained. This is in line with the predicted indoor coverage ranges. Note also that the upper right part of the walk path is in line of sight – the TRP is located so that it can be seen from above over the lower right walk path. These two parts have the best coverage along the measured path.

IV. CONCLUSIONS

Very good coverage is demonstrated with a massive MIMO NR testbed on 3.5 GHz. 700 Mbps DL throughput on an 80 MHz wide carrier is achieved at 700 m distance in LoS. In a dense urban microcell deployment 200 Mbps can be served also in non-LoS within intended cell range.

The massive MIMO enabled beamforming gain is larger than the additional propagation loss compared to a 2.1 GHz LTE band. This is very promising for 3.5 GHz NR deployment on existing LTE site grid (for example EUTRA bands 1, 3, 7, 33, 38, 40, 41, 42, 43, 48). Indoor coverage is also predicted to be feasible and on par with LTE. In older type of buildings coverage in whole cell area is expected while indoor solutions are likely needed in selected modern buildings, as for LTE. The measured indoor coverage was in line with predictions.

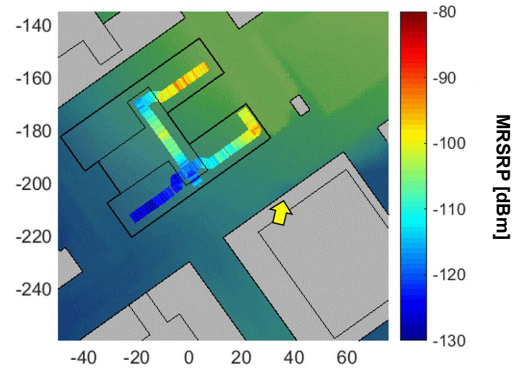


Figure 12. Coverage along a walk path inside an office building (House A). Yellow arrow indicates the location and direction of the TRP. Axes are scaled in m.

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