Rural ICT Testbed - #fulltäckning

Rural Broadband Connectivity Solutions

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INNEHÅLL

1 INTRODUCTION

Provision of omnipresent broadband connectivity is particularly challenging out in the rural. This document descibes the technical approaches taken in project "Rural ICT Testbed – #Fullcoverage", to accomplish this. We identify a bottom-up and a top-down perspective, complementary and feasible, that will provide solutions, along with important regulatory and other non-technical issues, described in other project reports.

CHALLENGES IN PROVIDING FULL RURAL COVERAGE

Providing rural area coverage is primarily a problem of economy. Globally there are 3.5 billion unique mobile subscribers using mobile networks to access the Internet, while 3.8 billion people remain offline. This connectivity gap can be further divided into a gap of 1.2 billion people, people that do not have coverage (***coverage gap***) and 2.5 billion people that have some coverage but are still not connected (***usage gap***). By the end of 2017 the global LTE population coverage reached around 55 percent, and this is forecast to grow to more than 85 percent in 2023. The connectivity gap (both coverage and usage gaps) typically relate to connectivity where people live and work.

In addition to the connectivity gap, there is also a large ***area gap*** affecting local businesses (e.g. in farming, forestry, tourism, logistics, transportation sectors) even in countries with highly developed cellular infrastructure. In Sweden for example the 4G coverage already reaches 99% of the population, however “sufficient broadband services” (defined as 30 Mbps in downlink (DL) and 256 kbps in uplink (UL)) is only available in 10.8% of the land area, while the government target is that this shall be available everywhere by 2025.

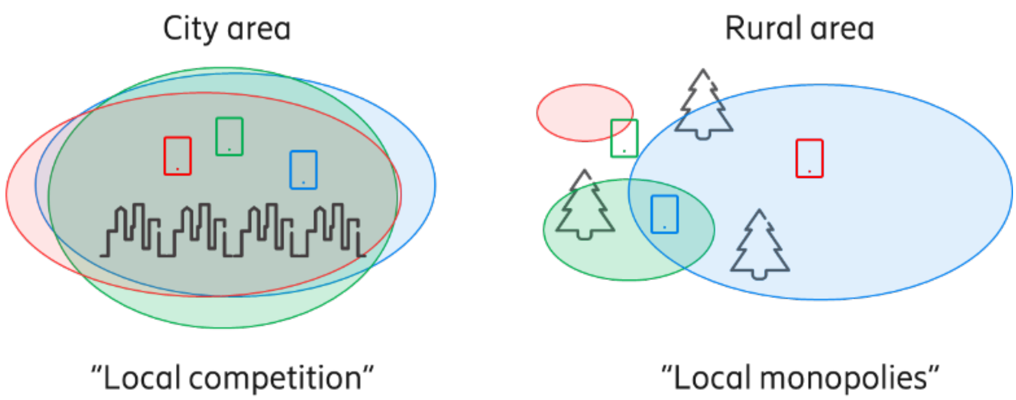

Figure 1: Where the “operator competition” model breaks down “local monopolies” emerge.

As a rule of thumb, deploying infrastructure in rural regions typically doubles the cost and provide ten times less revenues. The laws of market competition between network operators that constantly evolve service quality in urban/sub-urban areas are out of force in rural areas. This blocks the digital development of embedded societies (and related businesses), see Figure 1. In rural areas, if there is a service at all, a single operator (or several operators on shared low-grade infrastructure) provide poor grade service, in a local monopoly.

In order to break these local monopolies in under-served rural areas, network expansion needs to be driven not only by operators but also ***by regulators*** (for instance, through license conditions), ***by governments*** (for instance through funding for national security and public safety (NSPS) networks), and ***by end users*** (for instance through private networks, customer premise equipment (CPE) installations, access to spectrum, etc).

APPROACH AND METHODOLOGY

This document aims to describe *viable technical solutions* that provide full rural coverage “society sites”, that is, a rural citizen broadband network. Figure 2 depicts the various technical components. First, extreme-range umbrella cells provide voice/data/IoT access to users and homes directly (fixed-wireless access). They further provide backhaul functionality to relay stations thus establishing a local wired/wireless small-cell access hot-spot.

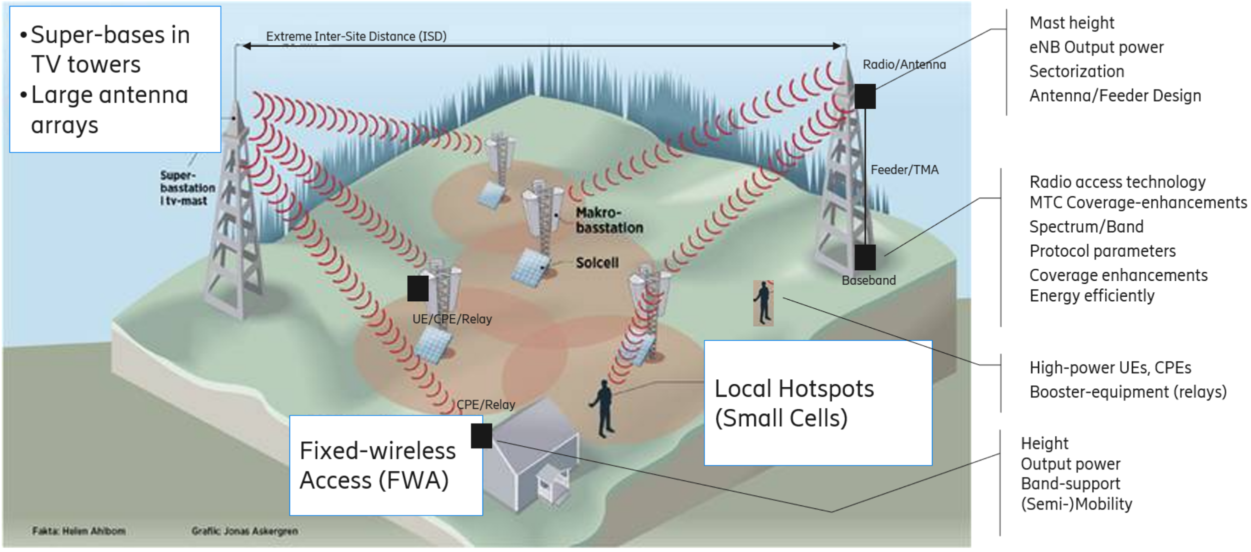

Figure 2: Full coverage: A combination of exteme-range umbrella cells and local hotspots.

Our methodology is to establish an inventory of applicable networking technologies (cellular, WIFI, satellite) in combination with sharing and roaming models (spectrum, infrastructure, slicing). From this inventory we select the most proper solution in terms of

- performance (coverage, rate, cost),
- service support (mobile broadband voice/data, machine-type communication, public safety),
- energy consumption (energy efficiency, powering methods), economic fit (capex and opex),
- local hotspot operator neutrality.

2 RURAL HOTSPOTS

With a bottom-up perspective, this chapter describes the technical solutions that provide local, high-quality connectivity. The ***rural hotspot*** can deliver different types of services depending on its pre-requisites.Two base requirements determine the capabilities of a rural hot spot: ***power*** and ***backhaul-connectivity***. Power can be delivered from the public electricity networks or from an energy-harvesting or energy-storing local source (for instance in a combination of wind power, solar cells and batteries). Backhaul connectivity can be provided by fibre, by a radio link or by using umbrella cells. The type of services that can be provided by the hot spot is dependent on the possible data rate that can be provided in the back-haul solution.

The rural hotspot can be either an indoor solution (providing connectivity within a building) or an outdoor solution (providing coverage in outdoor areas that might not be of commercial interest for the public operators).

If the backhaul provides high data rates the rural hotspot will be experienced like any other mobile network, providing both voice and high-speed data services in its coverage area. In other cases where the available backhaul speed is poorer only voice calls can be provided. The next sections illustrate these concepts.

LIMITED BACKHAUL: INDOOR VOICE HOTSPOT

In case the distance to any public mobile network or Internet connection is long (no nearby internet connection) a solution that uses existing mobile network as a backhaul can at least provide voice services and low data rate services (GPRS). This is illustrated in Figure 3.

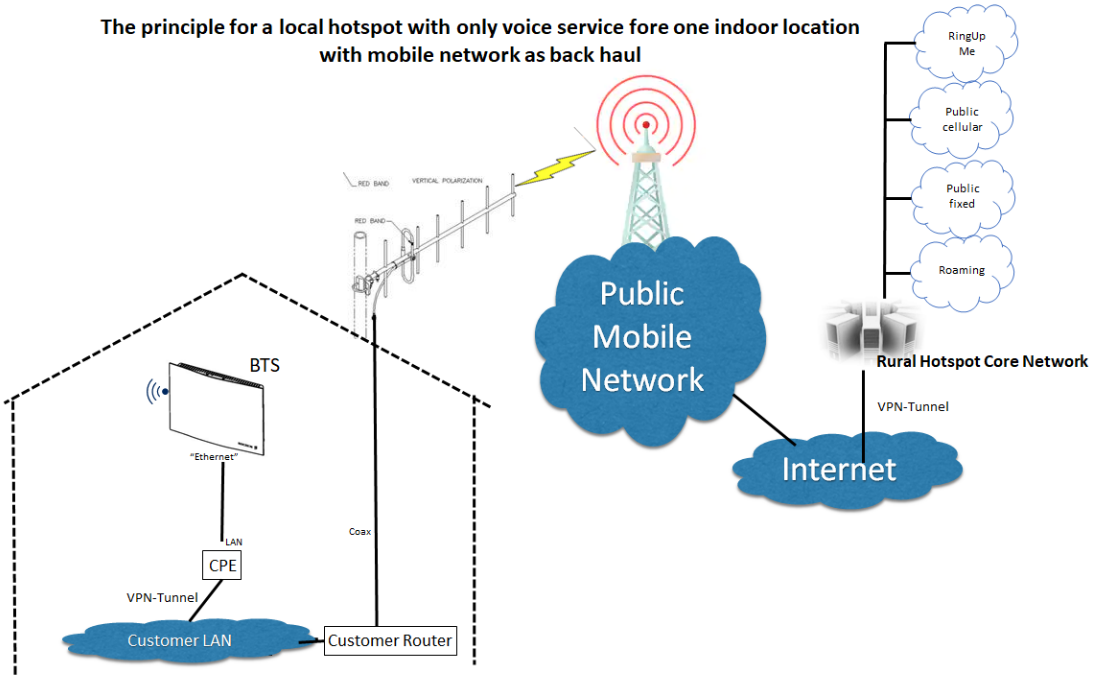

Figure 3: Low Bandwidth backhaul, a hotspot that at least can provide mobile voice coverage indoors

LIMITED BACKHAUL: OUTDOOR VOICE HOTSPOT

Similar to the above scenario, in case the distance to any public mobile network or Internet connection is long (no nearby internet connection)a solution that uses existing mobile network as a backhaul can also be deployed to provide limited outdoor coverage, as illustrated in Figure 4. This example hotspot provides for instance hikers in the mountains with enough coverage to make calls, emergency calls, send SMS and use GPRS data.

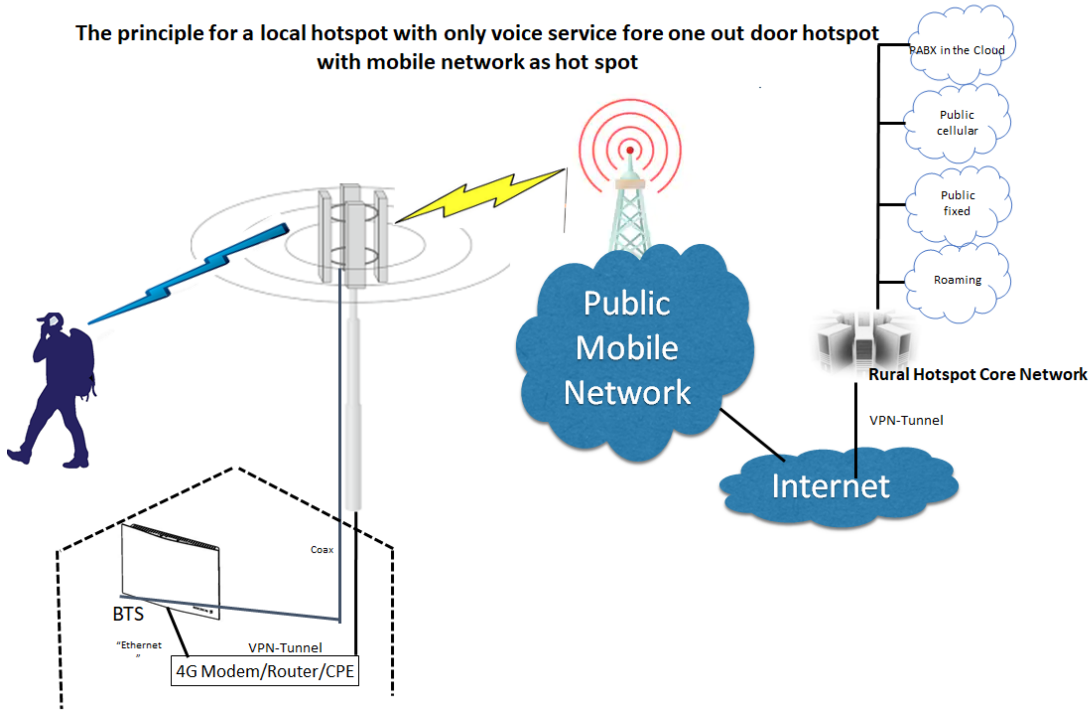

Figure 4: Low Bandwidth backhaul, a hotspot that at least can provide mobile voice outdoors

HIGH-SPEED BACKHAUL

In a third deployment, in case there is a nearby high-speed Internet connection (fibre backhaul or another high-speed Internet connection) the rural hot spot provides both voice and high-speed data.

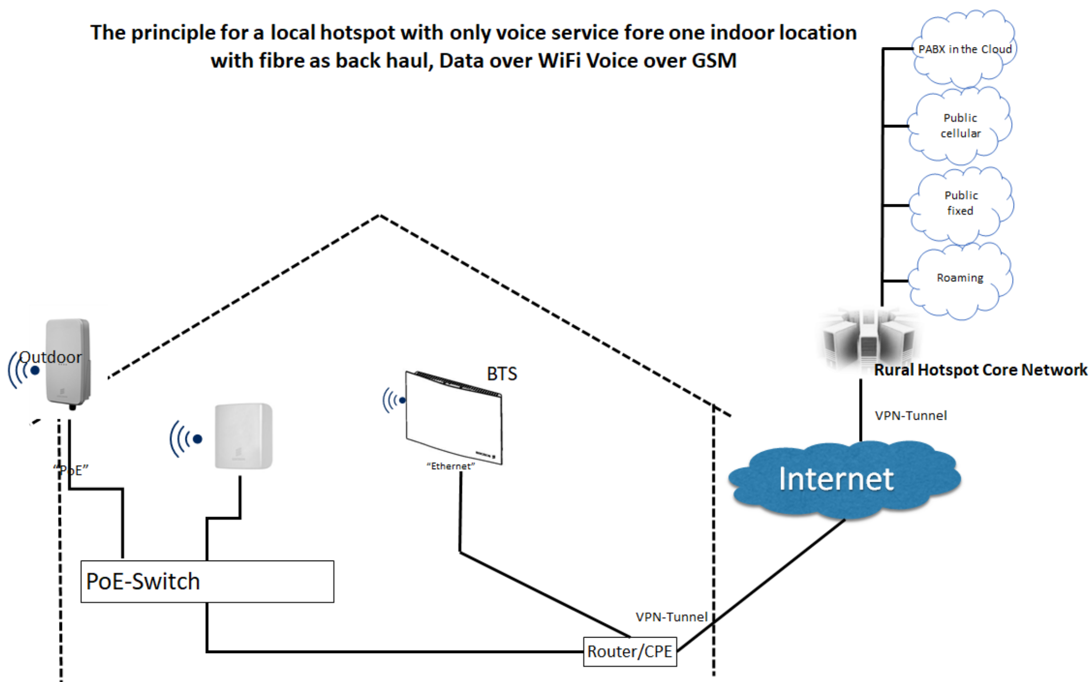

Figure 5: High Bandwidth backhaul, a hot spot that can provide both high speed data and voice calls

ROAMING TO THE PUBLIC NETWORK

The above-described technologies are today available on the market and can potentially be deployed without delay. However, practical use and value of these hotspot solutions depend not only on the technological solutions and deployments described above, but also on an the possibility for users to roam across different networks.

National roaming will be needed to give these networks its true value, to make this technology useful, and have it work as a neutral hotspot network. Two ways forward will be helpful in accomplishing this.

1. A will from public operators to let their subscribers roam into these rural hotspots
2. The regulator forces operators to offer roaming to neutral hotspots.

As a current interim solution and way to bridge the time until these steps are taken, it is possible today to provide sim-cards that have these local networks as home network, and can roam to the public networks. Subscribers of the public operators can make emergency calls from these local networks.

3 UMBRELLA CELLS: TECHNICAL SOLUTIONS

With a top-down perspective, this chapter describes the technical solutions that provide ultra-large umbrella cells. Focus in this project has been on terrestrial cellular technology like LTE, LTE advanced (LTE-A), machine-type LTE-M, and next-generation radio (5G NR).

Upgrading existing GSM sites with LTE or NR is an attractive first step to offer mobile broadband services to the part of the population under GSM coverage. In addition to this, providing full coverage to a country with a low number of radio sites requires selection of proper locations and improvements compared to a conventional (sub-)urban radio system. To exemplify, Figure 3 shows the TV-towers sparsely placed in northern Sweden used for DVB-T and FM radio with an average inter-site distance of approximately 114 km.

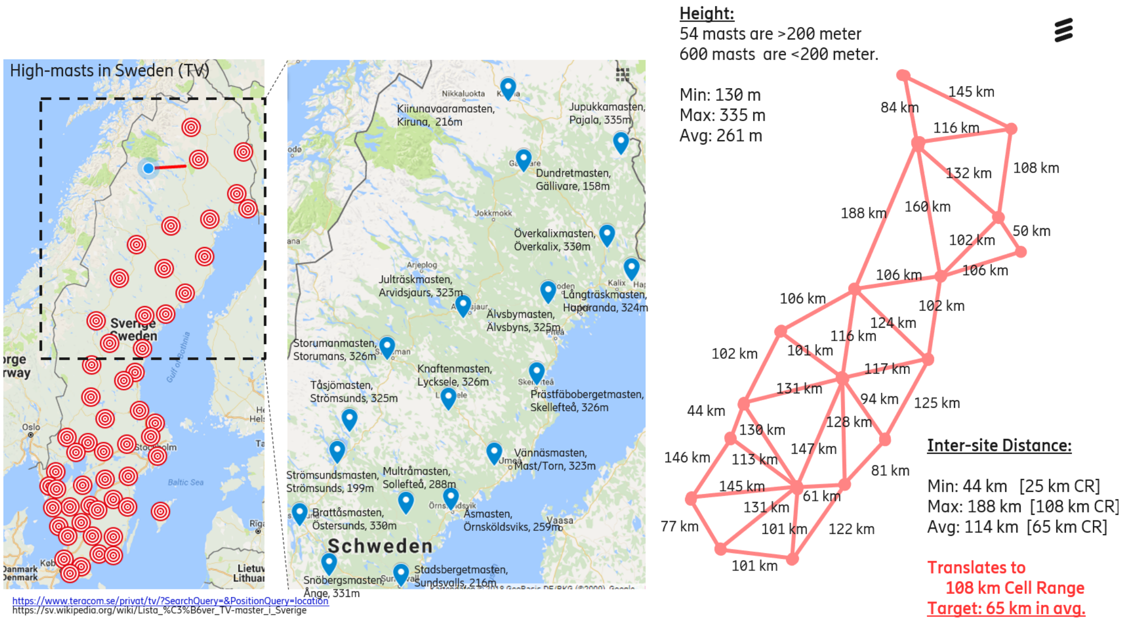

Figure 3: Network of Teracom TV-towers in North part of Sweden.

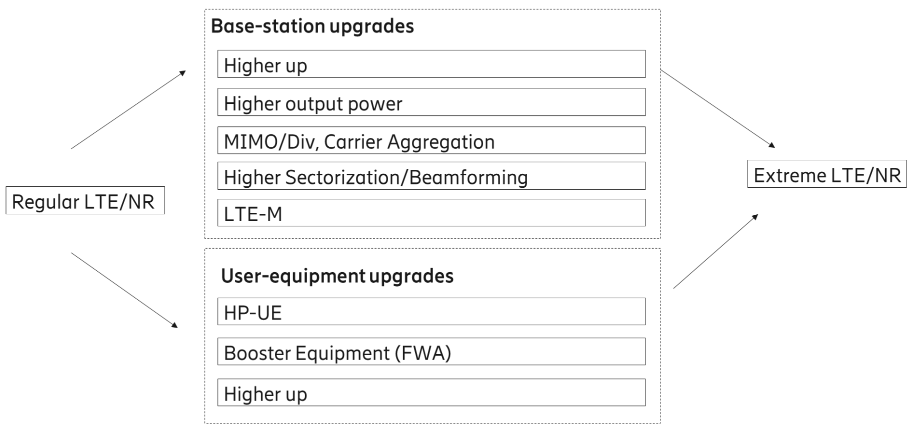

Figure 4: Possible base-station and user-equipment enhancements for extreme range operation.

To approach such a high reach, several enhancements are required, both on base-station and UE end, see Figure 4. At the base-station side the carrier frequency, antenna height, antenna placement, output power, and antenna gain have a large impact. Effective solutions on the network side are high sectorization (directional antennas), high beamforming gains, the use of MIMO and carrier-aggregation, more spectrum and bandwidth, and usage of carrier enhancements by protocol repetitions in LTE-M2.

ANTENNA HEIGHT

The most important factor to reach far is the mounting height of the antenna, i.e. tower height. As seen in Figure 5, at typical mast heights of 20-50 meters, each Decibel of more output power/antenna gain results in 0.5-0.8 km of longer reach, while at 500-meter heights, 1.7 km per Decibel are reached. With TV mast heights of 330 meters, 1.5 km/dB are found - this means that a high-tower system provides 3x coverage range over a regular radio system.

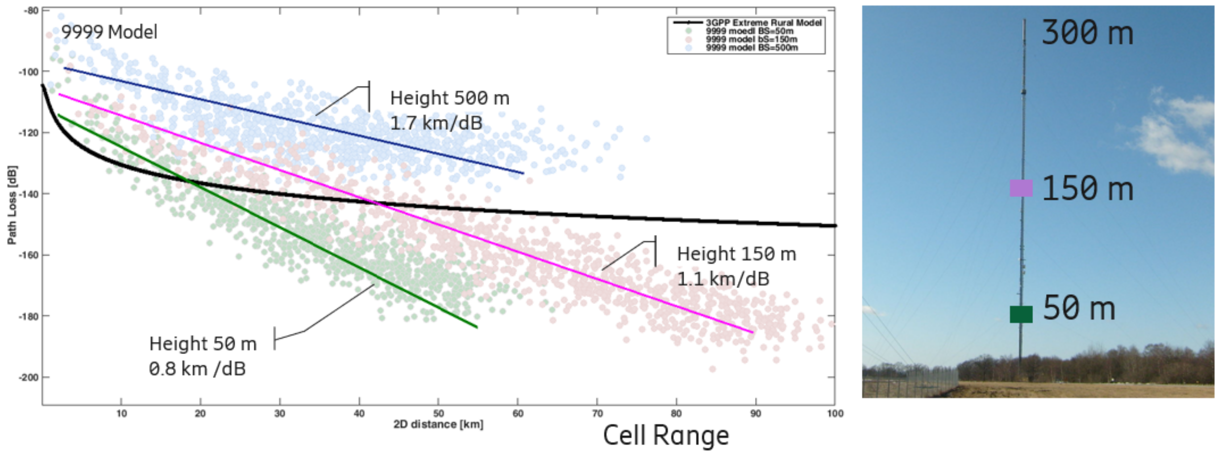

Figure 5: Path loss as a function of mast height.

HIGH-GAIN ANTENNAS

Radio systems are sectorized, i.e. one antenna covers a given opening angle, typically 120 degrees for 3 sectors or 90 degrees for 4 sectors. Such antennas provide a good trade-off between antenna size/weight and array gain. The table below shows typical gains for regular commercial antennas (12-19 dBi) including modular, high-gain antennas (22 dB for 6 sectors). By increasing the sectorization even further to 16 or even 25 sectors in combination with a small horizontal opening angle (null-filling design), antenna gains in the area of 30 dBi are reachable.

Such antennas are huge in size for low frequencies (for example 20m height times 5m diameter @450-800MHz), but sparse in antenna element area. On TV towers, there is enough space, but a highly optimized design is needed to provide lower weight, wind and ice load, see Figure 6.

Table 1: the effect of sectorization and modular high-gain antennas

Regular LTE sector antennas: (~9° azimuth HPBW)

3 sectors (120°)	+12 dB	[+ 12 km]	2m x 0,3 – 0,5 m
4 sectors (90°)	+15 dB	[+15 km]	
6 sectors (65°)	+17 dB	[+17 km]	
8 sectors (45°)	+19 dB	[+19 km]	

MHGA Antennas (~2° azimuth HPBW)

6 sectors (65°) +22 dB [+22km]

7m x 0.3 m

TABLE I: ESTIMATED ANTENNA DIMENSIONS FOR DIFFERENT HALF-POWER BEAMWIDTHS (HPBW). DIMENSION ESTIMATES BASED ON ANTMOD [3], GAIN FIGURES AS GIVEN IN [1].

Azim. HPBW (°)	65	65	90	90	45	30	22	14	11	7
Horizontal size (# of columns)	1	1	1	1	2	2	3	5	6	8
Elev. HPBW (°)	8	4	2	1	1	1	1	1	1	1
Vertical size (m)	1	2	4	8	8	8	8	8	8	8
Gain (dBi)	18	21	22	25	28	30	31	33	34.5	36

12 sectors 16 sectors 25 sectors

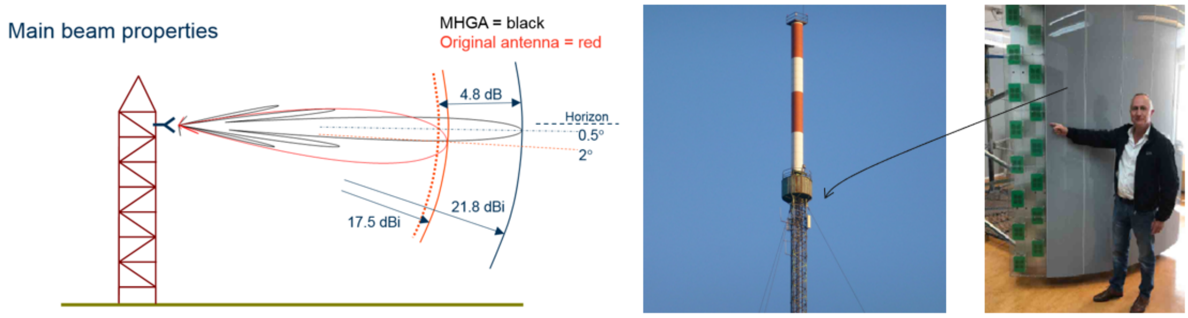

Figure 6: MHGA extreme sector antenna.

Category M – LTE

To enhance coverage for mobile telecommunications companies (MTCs), the cellular standardization body 3GPP has specified category M technology providing lower cost, higher coverage, and lower current. The basic technology behind is that data is repeatedly sent a couple of times (repetition coding) to improve reception. Each doubling of transmission attempts increases the link budget with 3 dB but halves the data rate. Coverage enhancement mode A uses 16x and 32x repetitions still providing Mbit/s capacity for broadband services while coverage enhancement mode B provides up to 2048x repetitions for kbit/s rates for very deep coverage targeting MTC devices only. Performance details on LTE-M can be found in the table below.

Table 2: LTE-M parameters

		LTE-M1	LTE-M2		
Attribute	CAT-1	LTE-M		NB-IOT	
		Rel 13	Rel 14	Rel 13	Rel 14
Spectrum	LTE bands	LTE bands Stand Alone (1.4MHz)		LTE Bands Stand Alone (200KHz)	
Typical MNO	LTE Coverage	Good LTE Coverage		Mix LTE and 2G	
Bandwidth	20 MHz	1.08MHz (CAT-M1)	5 MHz (CAT-M2)	180kHz	
Number of DL Antennas	2	1		1	
Duplex Modes	FD-FDD/TDD	HD-FDD, FD-FDD,TDD		HD-FDD	
UL Modulation	QPSK, 16QAM	QPSK, 16QAM		Pi/2 BPSK, Pi/4 QPSK	
DL Modulation	QPSK, 16QAM	QPSK, 16QAM		QPSK	
Spectral Efficiency	V.Good	Good		OK	
Power Class	Class 3 (23dBm)	Class 3 (23 dBm) Class 5 (20 dBm)		Class 3 and 5	* 14 dBm
UL Multple Access	LTE SC-FDMA	LTE SC-FDMA		LTE SC-FDMA + Single tone transmission with 3.75kHz and 15kHz bandwidths	
Coverage Extension	144 MCL	164 dB MCL		164 dB MCL	
Current (Idle Mode)	1-2ma (DRX)	<15 uA (80s eDRX)		<15 uA (80s eDRX)	
Data Rate	10/5 Mbps	300/375kbps (HD CAT-M1)	~590/1100kbps (HD CAT-M1) 2.35/1.5Mbps (HD CAT-M2)	27/65kbps (CAT-NB1)	~85/150kbps (CAT-NB2)
Resource Allocation	Dyanmic	Dynamic		Pre-allocated	Less Pre-allocated
QoS	Yes	Yes		No	
Mobility	Yes	Yes		No	
Real Time	Yes	Yes		No	
Voice	Yes	Yes ~2018	Enhanced	No	
Network Positioning	Yes (OTDOA)	Yes	Enhanced	No	Yes
Network Roll Out	Simple S/W Upgrade	S/W Upgrade		Mostly S/W Upgrade	
Network Availability	Many Networks	Q1-Q2'2017	~ Q3 2018	Q1-Q2'2017	~ Q3 2018

High-power UE, Booster Equipment

To drastically increase the service-range we need to address the terminal side - as uplink performance is limiting enhancing the UE transmission side is key to enable extreme coverage. The most important upgrade is higher power/better antenna transmission from the terminal (0.2W) towards the base-station (80W), see Figure 7.

Figure 7: Uplink problem limiting reach

An upgrade from a conventional Class-3 UE with 200 mW Tx power to Class-1 High-Power UE (HP-UE) providing 1.2 W with support of LTE-M2 provide notable link budget improvements. In fixed-wireless access deployments (FWA), UEs with external outdoor directional antennas that can be mounted in line-of-sight to the base-station further extend UL significantly coverage by avoiding loss due to buildings and vegetation.

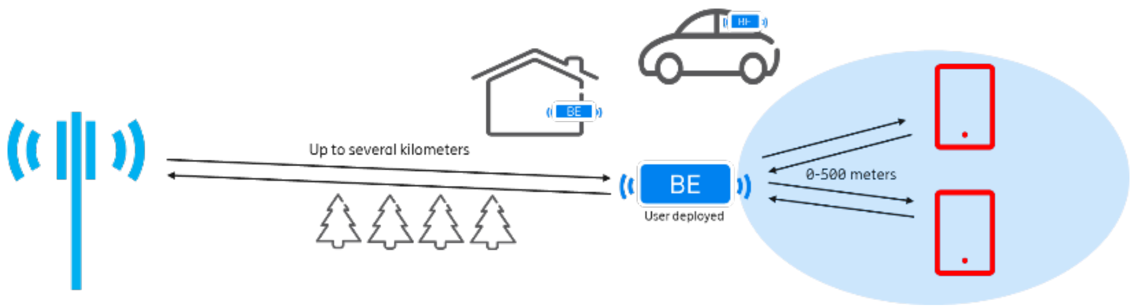

Figure 8: User deployed rural booster equipment (BE).

Relaying solutions are technically very efficient but due to miss-aligned incentives they are not yet widely used to solve rural coverage problems. For that to happen we need to enable the problem owner, i.e. the end-user suffering from poor service quality, to solve her own problem.

The "backhaul link" can be addressed by deploying high power terminals (e.g. 20W) with high gain antennas and by ensuring a good antenna placement. The "access link" can either be based on Wifi or 3GPP technologies. Wifi is inferior in terms of capacity, range, security, mobility, quality of service, etc but without any access to licensed spectrum end-users have no other option. By providing local spectrum licenses (e.g. property-based spectrum licenses) end users can have the option to also use 5G NR on the small rural hotspot. Such local licenses could preferably make use of higher spectrum bands (e.g. above 6 GHz). An example of a such solution, here denoted user deployed booster equipment (BE) is depicted in Figure 8. User-deployed BE may be placed in properties (utilizing property based local spectrum licenses) or in vehicles (utilizing MNO spectrum or un-licensed bands).

SPECTRUM

User deployed BE devices need to have access to a local spectrum license to effectively create a 5G NR rural hotspot. The common model of operators gaining access to licensed spectrum for exclusive national and multi-year usage has recently been complemented with new models for license leasing/sharing – LSA and SAS. Industrial sites using ultra-reliable machine-time-communication as well as rural hotspot deployments need access to local and short-term licensed spectrum at a reasonable cost and predicable quality of service. An evolved LSA architecture as shown in Figure 9 comprises a repository holding details of spectrum usage over space and time, as a-priori required by an incumbent, but also as granted to LSA licensees (like mobile network operators MNOs) under the supervision of the national regulation agency (NRA).

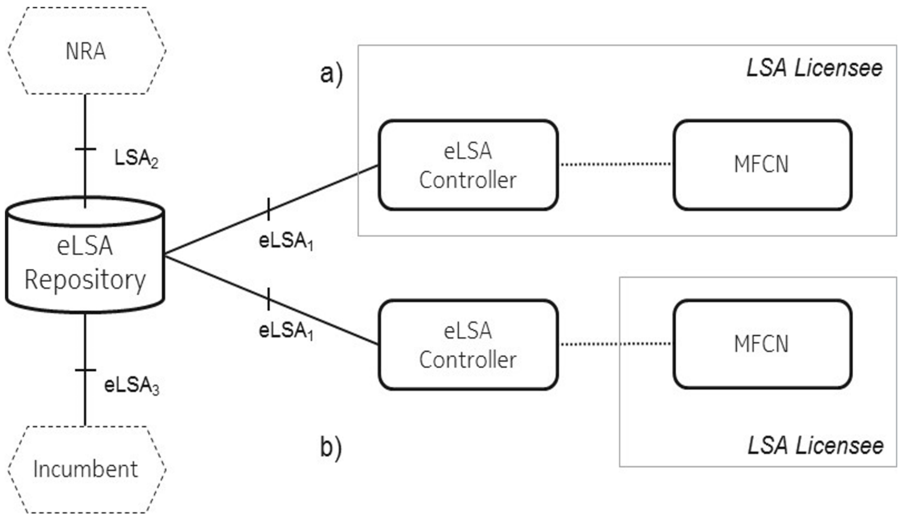

Figure 9: Licensed spectrum access reference architecture.

Based on this utilization information, MNOs can gain access to and release spectrum via eLSA controllers for exclusive use in mobile/fixed communication networks (MFCN) for a given duration in a local area. There are several alternative definitions of local area such as polygon-based, community, population-based (census tracts), but the most favourable being land ownership/real estate-based as these areas are already established in land registers. In many countries, the spectrum auction process of the 3.5 GHz band (3.4-3.8 GHz) are in the starting blocks with having LSA in mind. In Europe, beside classical national licenses, the new concept of "local license" to enable industrial and rural applications is adopted (e.g. Germany and Sweden in 3.7-3.8 GHz).

In the US, FCC promotes a similar but more general solution for the usage of the CBRS 3.5 GHz band. The basic idea of LSA is extended by coordinating licensed and unlicensed spectrum usage in a centralized SAS. Given the incumbent is not using the spectrum, a priority access license (PAL) is granted to licensees based on area definitions. If the incumbent and the PAL are not utilizing a frequency at a given place, general authorized access (GAA) is granted turning licensed spectrum into unlicensed. The main difference between LSA and SAS is, that in LSA the incumbent must provide a-priori information on planned spectrum usage whereas in SAS, the coordination of spectrum assignment is done dynamically using input from environmental sensors checking the incumbents' occupation of spectrum throughout the country.

4 UMBRELLA CELLS: PERFORMANCE EVALUATION

RE-USING THE GSM GRID WITH LTE AND NR

Rural areas are usually characterized by poor quality Internet and basic mobile coverage provided by GSM grids. The main reason that operators are reluctant to deploy new broadband infrastructures in these areas are the limited economic incentives. Therefore, in this section, we evaluate whether it is possible to deliver broadband and 5G to rural areas using existing GSM grids with conventional LTE 800MHz and/or NR 3.5 GHz. In an attempt to make the results applicable to all GSM networks, the coverage of the network is tuned to match that of a basic GSM voice service.

A network with a hexagonal layout of 7 macro sites mounted on towers of 25 m height is assumed as shown in Figure 10. In this service area UEs are uniformly distributed, each having an antenna height of 1.5 m. Half of the UEs are located indoors in low-loss buildings, and the other half are located outdoors in cars. The map together with the nodes are assumed to be wrapped around the edges of the service area to reduce border effects. The ITU rural macro (RMa) propagation model and the spatial channel model (SCM) described in [15] are applied in the simulation. This model is applicable to an inter-site distance (ISD) of up to 5 km. Three deployment scenarios are evaluated:

- *LTE 800 MHz*
- *NR 3.5 GHz standalone; and*
- *LTE 800 MHz and NR 3.5 GHz with DL aggregation.*

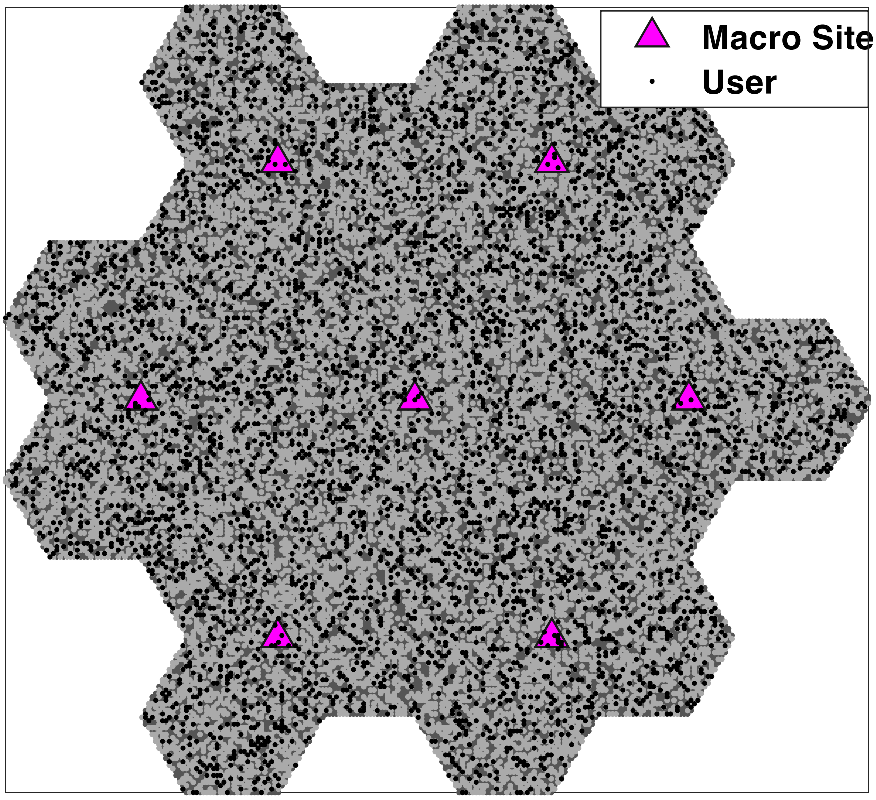

Figure 10: The network layout consists of 7 sites with 3 cells per site (21 cells).

For LTE 800 MHz, a 3-sector antenna, each sector with a fixed 5×1 array, is assumed. For NR 3.5 GHz, each antenna array has 64 dual-polarized antenna elements (8 rows and 8 columns), and the elements are paired into two subarrays on each column, making the antenna array a 2×8 array of 4×1 subarrays. Omni-directional antennas are used at the UE end.

With the considered propagation model, we first need to define the ISD representing a typical GSM grid. The maximum supported coupling loss for GSM is approximately 137 – 144 dB to support decent control channel signalling, and here we assume that a maximum of 140 dB coupling loss is needed for basic coverage. If the propagation losses are similar for LTE at 800 MHz and GSM at 900MHz, we search for an ISD that results in 140dB coupling loss (or equivalently -140dB coupling gain) at the cell-edge for LTE at 800MHz.

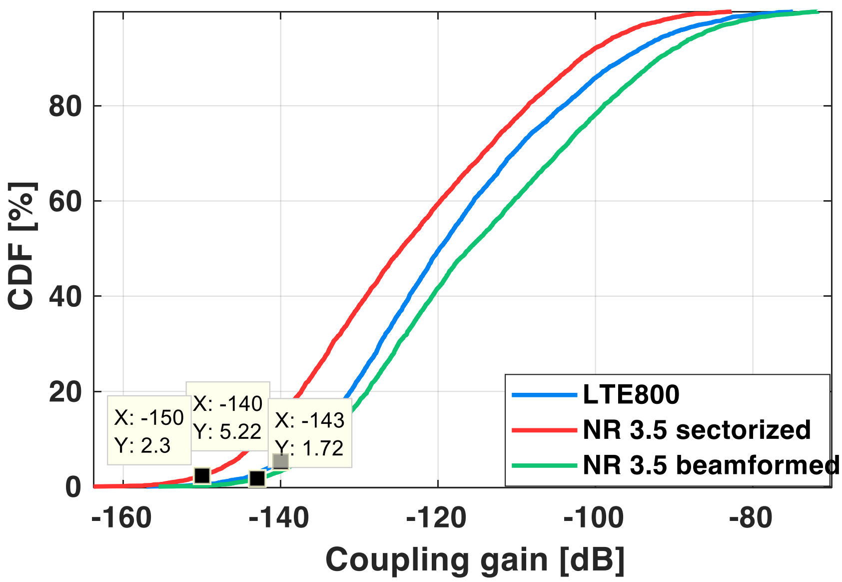

Figure 11: CDF of the coupling gain (ISD: 4km). For NR sectorized: array gain excluded. For NR beamformed: array gain included.

Figure 12 shows that -140dB coupling gain at the 5th percentile occurs at an ISD of 4 km. Note that the ISD of 4 km is tightly connected with the propagation model assumed in evaluation, and that both smaller and larger ISDs can be obtained with other propagation models, but that the results in terms of coverage are representative for all of those. In terms of NR, the common control channels, e.g. SS/PBCH block (SSB) support a coupling loss of 145 – 150 dB, and for beamformed control channels such as PDCCH and PUCCH, a beamformed coupling loss of approximately 143 dB should be supported [16]. At the same ISD, Figure 11 also shows the sectorized (for common control channels) and beamformed coupling gain at NR 3.5 GHz. The figure demonstrates that a decent control channel coverage can be reached (150 dB coupling loss at 2.3th percentile and 143 dB beamformed coupling loss at 1.7th percentile).

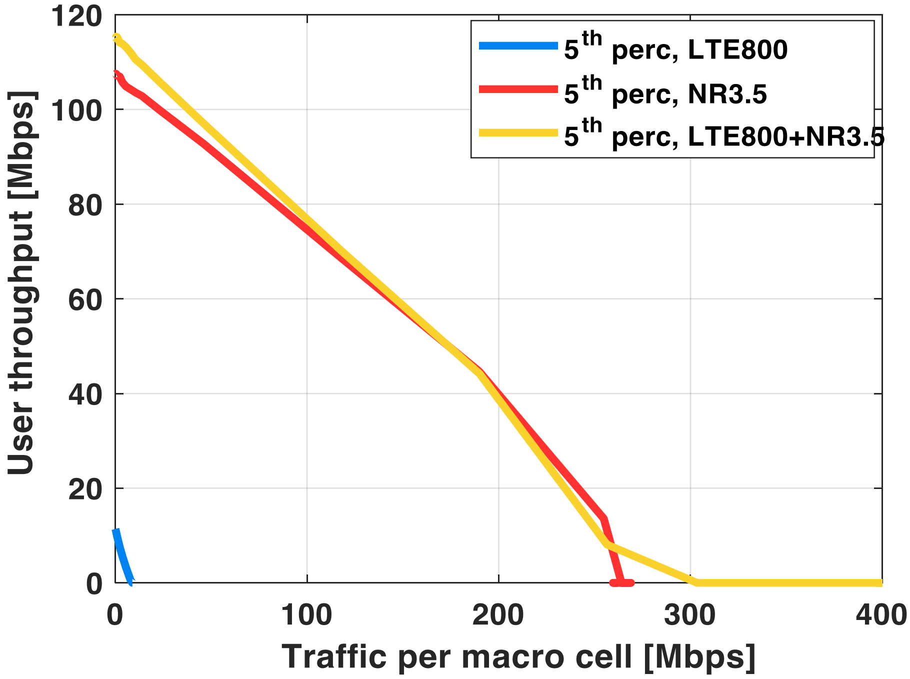

Figure 12: Downlink user throughput – 5th percentile (ISD: 4km).

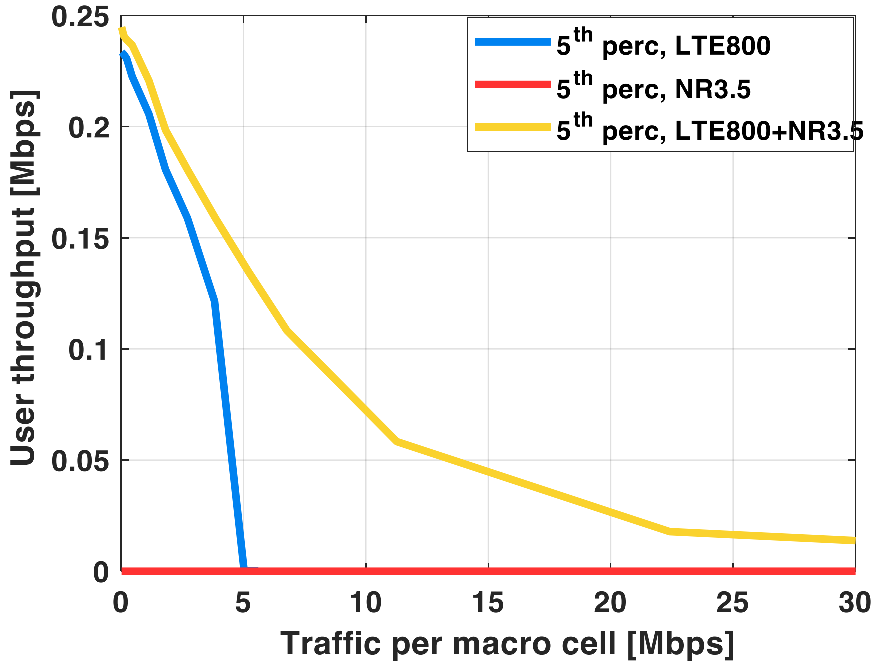

Figure 13: Uplink user throughput – 5th percentile (ISD: 4km).

Figure 12 and 13 show the DL and UL user throughput in the mentioned deployment scenarios. For DL, over 20 times capacity gain can be achieved by utilizing NR 3.5 GHz compared to LTE 800 MHz, thanks to the wide bandwidth the 3.5 GHz band can offer as well as the advanced BS antenna array and transmission scheme deployed. Downlink data rates for cell edge users of over 100 Mbps can be reached with 5G NR using conventional UE terminals. However due to the limited UE transmit power (23 dBm) and unfavourable propagation conditions, a NR 3.5 GHz standalone network cannot provide adequate uplink coverage for cell edge users (with zero user throughput across different traffic loads). In this case, an LTE/GSM grid is needed to provide some basic uplink coverage. Nevertheless, adding the NR 3.5 GHz band still proves to be a promising approach to increasing the uplink capacity by offloading the traffic from the existing LTE grid at 800 MHz. To address the uplink coverage issue for a NR standalone network, the potential upgrades including increasing the antenna height for the base stations and the usage of high-power user deployed BEs with directional antennas may need to be incorporated into the network design for rural scenarios. These are discussed in the following section.

HIGH-POWER, HIGH-TOWER FOR EXTREME RANGE RURAL COVERAGE

Although the DL performance can be significantly improved by using NR 3.5 GHz, uplink coverage is still the main bottleneck. With the potential upgrades mentioned, we examine the feasibility of providing extreme rural coverage by utilizing a NR 3.5 GHz standalone network.

Assuming the same hexagonal network layout as shown in Figure 6, here a network operating only at NR 3.5 GHz is assumed. The macro sites are located on TV masts with a height of 300 m, and large inter site distances (ISDs) ranging from 40 km to 80 km are used to reflect the distances between TV masts. In addition, we assume high-power user deployed BE are uniformly deployed outdoors either on rooftops or poles of 10 m high.

The same antenna configuration for NR described in Section V is assumed at the base station side. At the UE side, two antenna configurations are compared. One is an omni-directional antenna, and the other is a directional antenna with 1×4 dual-polarized antenna elements, providing an azimuth coverage of 360°. Due to the large ISDs considered, the Ericsson 9999 propagation model for rural areas is assumed [17]. This distance (d) (in km) dependent model is applicable to rural areas with trees, bushes and houses, and can be calculated by:

$$PL = a_0 + a_1 log_{10}(d) + a_2 log_{10}(h_b) + a_3 log_{10}(h_b) log_{10}(d) - 3.2(log_{10}(11.75h_r)^2) + g(f)$$

where *g(f)* is defined by

$$g(f) = 44.49 log_{10}(f) - 4.78(log_{10}(f))^2$$

here f is frequency in MHz, h_b and h_r in meter are base station and receiver height respectively, and a_0, a_1, a_2, a_3 are constant values for different terrain types. For a rural scenario, a_0 is 51.5 for 3.5 GHz and 42.3 for 800 MHz, a_1 =34, a_2 =-12, and a_3 =0.1. In this case no calibration of the coverage to that of a TV system has been made. We note however that at distance of 60km the propagation model results in an excess loss (additional loss compared to free-space) of 30dB, which leaves room for propagation losses (e.g. due to diffraction or foliage) of that magnitude.

With the potential upgrades listed in Figure 4 at both base station side and UE side, Figure 14 and 15 show the end-user throughput with different ISDs and UE antenna configurations.

Table 3: parameters in the evaluation

Parameter	**Value**	
	LTE 800 MHz	***NR 3.5GHz***
Bandwidth	Downlink: 10 MHz Uplink: 10 MHz	*100 MHz for downlink and uplink*
Duplex scheme	FDD	*TDD: 25% uplink; 75% downlink*
BS antenna	3 sector antenna (fixed 5×1 array); max. gain: 15 dBi	*Antenna array with (2×8) × (4×1) dual-polarized elements; max. gain: 26 dBi*
BS antenna horiz./vertical elem. separation	-/0.6 λ	*0.51/0.68 λ*
UE antenna	Omni-directional: -8dBi gain; 2-branch diversity	*Omni-directional: -3dBi gain; 4-branch diversity*

Parameter	**Value**	
	LTE 800 MHz	***NR 3.5GHz***
		Directional: 1×4 dual-pol. elem; gain: 12 dBi; horiz. elem. separation: 0.5 λ; 4-branch diversity
Channel model	*Spatial channel model for RMa*	
BS transmit power	60 W	*200 W*
BS noise figure	2 dB	*4.5 dB*
UE transmit power	23 dBm	*23 dBm (Section V) 43 dBm (Section VI)*
UE noise figure	6 dB	*7 dB*
Transmission scheme	Two layer SU-MIMO	*MU-MIMO, reciprocity-based beamforming*
Traffic Model	*Packet download, equal buffer.*	

Compared to the results from the GSM grid, both plots demonstrate significant performance gain achieved by increasing the antenna height for both BSs and UEs, i.e., mounting the BS on TV masts and using user deployed BE on rooftops.

In addition, the UE equipment upgrades play an essential role in improving the uplink performance. With high power (43 dBm) directional UE antennas, uplink user throughput at an ISD of 80 km can reach 5 Mbps at cell edge at low traffic loads, and 120Mbps for downlink. With omni-directional UE antennas, the ISD need to be reduced to 40 km to achieve similar performance at cell edge. Although not shown here, good control channel coverage can be supported across all different ISDs tested, for example, 150 dB coupling loss at 2th percentile for ISD 80 km.

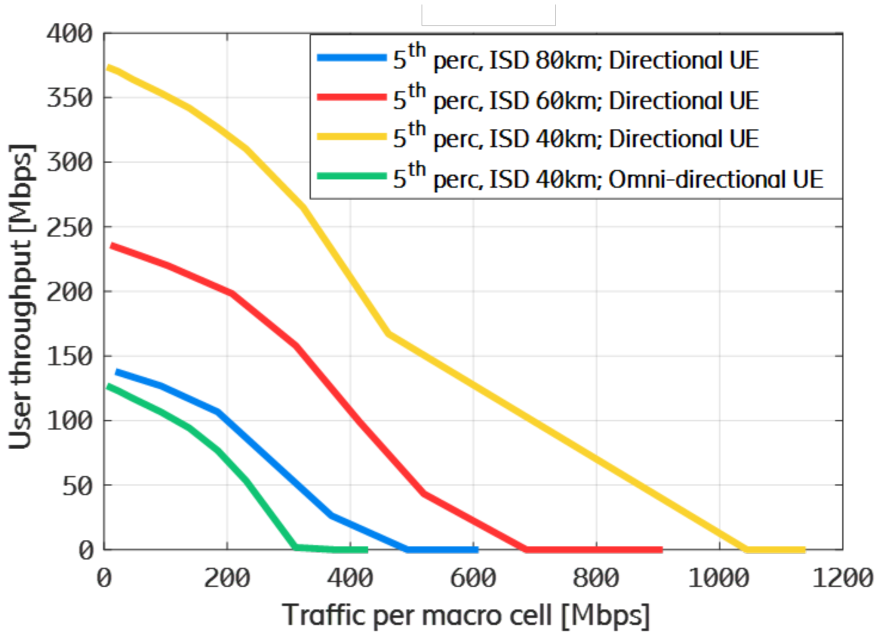

Figure 14: Downlink user throughput – 5th percentile.

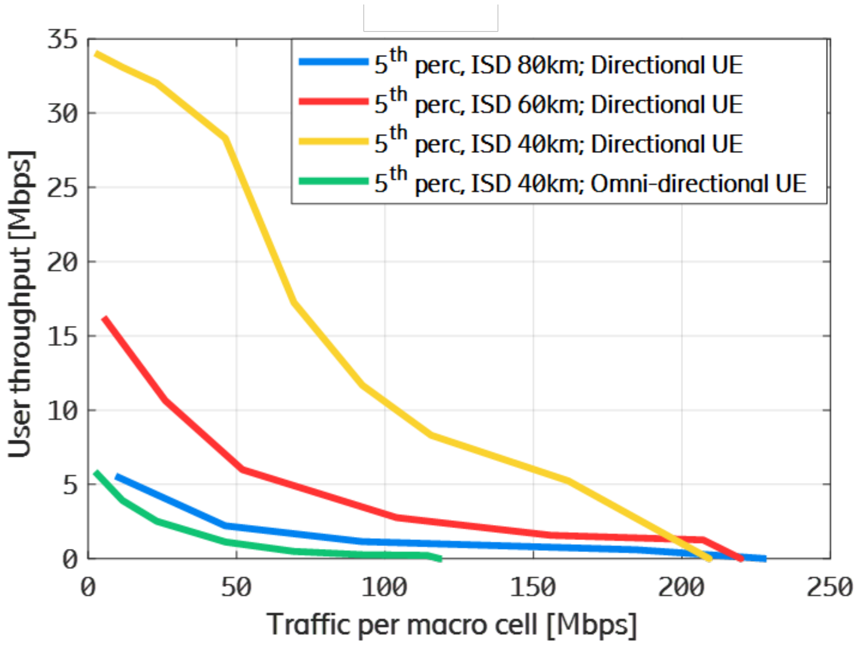

Figure 15: Uplink user throughput – 5th percentile.

5 SUMMARY AND CONCLUSIONS

This report has described the two technical approaches taken by the project. On one hand, a bottom-up approach realizes what we refer to as rural hotspots, oases of high-quality connectivity, the speed of which with the remote Internet depends on the presence and quality of a backhaul.

We conclude that technologies exist today to realize these hotspots, and we have identified a strong need for roaming alternatives between these neutral local networks and the existing national cellular operators.

On the other hand, we have presented solutions from a top-down approach in what we refer to as umbrella cells. These cells rely to a large extend on the presence of today's TV infrastructure, as the mounting height of the base station antenna has a significant impact on the cell radius of these umbrella cells. We show that this concept, relying on a number of sub-technologies (high-gain antennas, sectorization, boosted UEs, etc) can provide ubiquitous coverage in Sweden (cell radii in the order of 80km) by essentially deploying the existing TV infrastructure.