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EXTREME LONG RANGE COMMUNI- CATIONS FOR DEEP RURAL COVERAGE

(INCL. AIRBORNE SOLUTIONS)



Extreme Long Range Communications for Deep Rural Coverage (incl. airborne solutions)

by NGMN Alliance

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Abstract:

In this document reasoning for providing coverage for sparsely populated areas are presented along with a number of Mobile and Satellite Technologies that could provide coverage to remote areas.

There is a sound business justification to provide affordable Voice and Data Services for sparsely populated areas, such as Sub-Sahara Africa, but also for higher ARPU markets with wide rural areas, such as North Canada. Mobile network operators worldwide have both economic and social incentives to offer services to rural residents, but efficiently serving dispersed populations with current technologies is difficult and rural access lags significantly behind urban access.

For many network operators, who want to expand addressable markets and satisfy users interest or who under regulatory obligations or social responsibilities willingness must cover vast areas of sparsely populated regions, a cost-effective technology is essential which on one hand provides adequate voice and data services and other hand is economically sustainable to deploy and to maintain.

The purpose of the NGMN's Extreme Long Range Communications for Deep Rural Coverage program is to explore the challenge of addressing rural markets and to create industry momentum around long range communications solutions that are suitable for offering Internet access to rural populations who are underserved today.

A number of options exists for operators to provide coverage; these are:

- i. Extending the range of the existing macro sites to up to 40 Km cell radius, where possible
- ii. Building new sites for extending coverage into coverage voids, with the highest possible cell radius to maximize population uptake. Suitable locations for new sites would be based on geographical coverage and statistical population growth
- iii. Infrastructure sharing between operators, where regulatory environment allows, operators can offer National Roaming between their networks to share subscribers
- iv. Utilising Relay nodes to connect to Remote sites
- v. Wireless backhauling where the LTE or the NR (5G) spectrum is used to backhaul the traffic from the Remote Site to the Core
- vi. Utilising Satellite Backhaul to connect the Remote Site to the Core

In reflection, a number of technologies are at hand that can provide services to sparsely populated areas and two categories require careful considerations:

Category 1- Network Implementations: In this document, we have presented a number of technologies that are at hand which could provide coverage to remote locations, and network operators must find a balance between practical deployment options, deployment costs and projected revenues

Category 2- User Equipment: considering that users from emerging markets in these deep rural environments have low income and cannot afford expensive smartphones, and considering large number of users in these remote areas, there is a practical business rationale for developing low-cost smartphone with new "Long Range Features"



By focusing effort directly on rural connectivity requirements, NGMN can play a role in better connecting these important populations. Technological areas that NGMN could have an influence are as follows:

- Smartphones with Coverage Extension capabilities and wide bandwidth capabilities. By making IoT-type coverage enhancement standard features of smartphones, MNOs can see increased cell radius for voice and messaging applications, in addition to improved reliability on these services in a range of environments
- Wider deployment of Node Relay technologies for extending the cell coverage and helping to lower deployment costs for MNOs
- Encouraging the integration of Non-Terrestrial Networks (NTN) with greatly expanded reach can help MNOs to provide some level of service to most or all of their territory. NTN applications are seen twofold: Non-Terrestrial Networks (NTN), where GEO, MEO or LEO Satellites provide direct LTE or NR(5G) coverage to the users without having to deploy traditional ground based RAN equipment. Utilising inexpensive Satellite backhauls by using LEO Satellites which are either have already been launched or will be launched in the near future
- Development of cost-effective Terminals with wide connectivity options for either Ground Based Long Range Cell Technologies or Direct Connectivity to Satellite Service

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1 INTRODUCTION

Mobile network operators currently offer telephony in almost every major urban centre around the world. Falling costs for 3G and 4G equipment and handsets are helping mobile network operators in even the poorest cities to provide broadband access. However, over 3 billion people live in rural areas [1], and within the United Nation's Least Developed Countries list, 66% of the population is rural. Mobile network operators worldwide have both economic and social incentives to offer services to rural residents, but efficiently serving dispersed populations with current technologies is difficult and rural access lags significantly behind urban access.

The purpose of the NGMN's Extreme Long Range Communications for Deep Rural Coverage program is to explore the challenge of addressing rural markets and to create industry momentum around long range communications solutions that are suitable for offering Internet access to rural populations who are underserved today.

2 BUSINESS RATIONALE

2.1 Statement of the problem with business rationale

According to the International Telecommunications Union [2], Internet penetration figures at the end of 2018 show that more than 3.9 billion people, representing 48.8% of world's population, are not connected to the Internet. More specifically, 74.6% of people in Africa still lack basic Internet access. Although part of the population living in dense areas can already access Internet thanks to 3G and 4G networks, the major part lives in low density rural areas. This implies that there are still significant opportunities for telecom operators to tap into by offering basic Internet services to unconnected rural residents. Although coverage extension is a key issue for mobile network operators, cellular market models and technology solutions driven by mature economies are not adequate and sufficiently tailored to capture the potential of such underserved markets.

The reason why nearly 50% of world population is not connected to the Internet is twofold. On the one hand, affordability for the low-end users is constrained by the profitability threshold for MNO. In the affected areas, the profitability suffers on one side from low population density in the cell coverage, low penetration ratio and on the other side from the costs to build radio access infrastructure and to interconnect the site to the core network, among other factors. As a result of that, many users can't afford Internet (both device and connectivity) even if there is network coverage where they live. On the other hand, many people can't access the Internet simply because there is no coverage where they live. Some of them are going several km away from where they live to get connectivity.

Regarding voice services, according to GSMA 2018, the Sub-Saharan Africa has achieved near-universal 2G coverage: on average 90% of the population were covered by 2G networks as of the end of 2017. But there are several countries that are far below this average, typically in the center of Africa or where the road conditions are harsh (e.g., due to the presence of mountains, vegetation, floods ...) or when a large portion of the population is spread across more than 70% of the territory.



It is also interesting to compare Internet usage and quality between continents: most recent figures we found (2016) are showed in Table 1 (source: <https://www.itu.int/en/ITU-D/Statistics/Documents/publications/ldb/LDB ICT 2018.pdf>)

	Population covered by at least a 3G mobile network	Individuals using the Internet	International Internet bandwidth per Internet user
World	85%	45.9%	78.8 kbs
East Asia & Pacific	95%	52.8%	71.1 kbs
Europe & Central Asia	91%	73.9%	144.6 kbs
Latin America & Caribbean	92%	56.4%	61.6 kbs
Middle East & North Africa	83%	47.6%	42.5 kbs
North America	100%	77.5%	128.3 kbs
South Asia	79%	26.5%	15.5 kbs
Sub-Saharan Africa	58%	20%	47.7 kbs

Table 1 : Internet usage per world region

2.2 5G Standardization requirements regarding Extreme Coverage in low density areas

The 5G standardization process is an opportunity to rethink technologies and network operating models to better address challenges related to low density areas (typically in emerging markets) and to develop cost efficient solutions to offer Internet access there. Moreover, coverage extension is also a key issue in many harsh areas everywhere in the world and not only in emerging markets, such as deep indoor (e.g., parking), maritime areas along the coast, isolated roads, small isolated communities...

Interestingly, in some contexts the capacity requirements can be lowered, typically in low-density areas (e.g., less than 5 inhabitants/km²)¹ according to the 3GPP TS 22.261 [3] requirements on Extreme long range coverage in low density areas and Markets requiring minimal service levels. The cell radius objective taken in this 3GPP study is to reach 100km, according to the maximum value defined for timing advance in LTE (taken as a reference). The maximum timing advance value poses a limitation to the coverage area achievable in the uplink, and although to that regard the 3GPP specifications allow theoretically a cell radius of 100 km, that is rather challenging to achieve in practical deployments. It is noted that the cell radius is 35 km for 2G GSM rural cells.

The statement regarding ‘extreme coverage in low density areas in TS 22.261 [3] is the following:

- The 5G system shall support the extreme long-range coverage (up to 100 km) in low density areas (up to 2 users/km²).
- The 5G system shall support a minimum user throughput of 1 Mbps on DL and 100 kbps on UL at the edge of coverage.
- The 5G system shall support a minimum cell throughput capacity of 10 Mbps/cell on DL (based on an assumption of 1 GB/month/sub).
- The 5G system shall support a maximum of [400] ms E2E latency for voice services at the edge of coverage

Energy efficiency is also a critical issue in 5G, included also in TS 22.261 [3]. The potential to deploy systems in areas without a reliable energy source requires new methods of managing energy consumption not only in the UEs but throughout all components of the 5G system Typically, up to 1 billion people still lack access to electricity, half of

¹ an order of magnitude of the ARPU in these areas is around 2\$ in Sub-Saharan countries. Moreover technical-economic studies including penetration ratio should take also into account that half of population is under 20 years old.

them live in Sub-Saharan Africa. Recent papers such as Armev & Hosman (2016) [4] and Mothobi & Grzybowski (2017) [5] start emphasizing about access to electricity as key determinant of ICT usage in developing countries. The lack of access to electricity increases the cost for deploying networks where there is no grid, but it also affects the use of Internet and smartphones (recharging), and even mobile telephony at a lower level.

2.3 Rural segmentation based on population distribution

Since profitability is challenging to reach with traditional 3GPP architectures in the underserved rural areas of interest in this report, we propose here a segmentation of rural areas based on population criteria and user traffic requirements to assess the existence and relevance of lower-cost solutions.

The first table gives typical values of population density and expected voice/data traffic of 3 different rural areas types, as well as associated configuration options for candidate technologies and cost reduction. Some of these areas can already be covered by 2G networks but no real capacity for Internet connectivity is provided there.

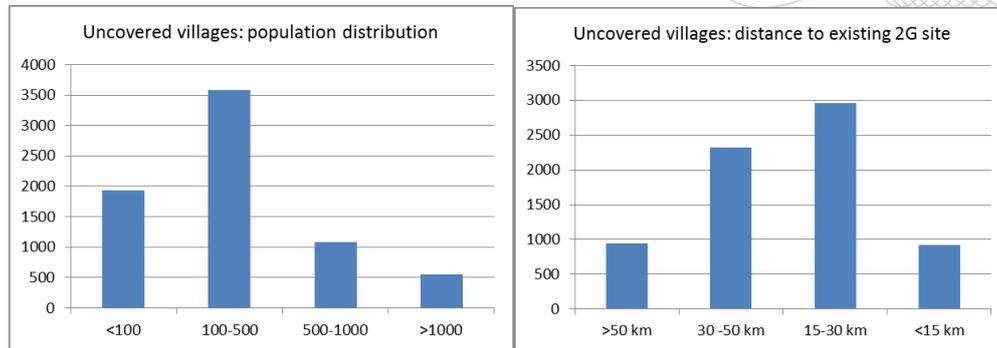
#	Description	Populated Rural Areas	Isolated groups of villages	Isolated small villages
1	Geography	Villages out of reach of existing data coverage but not isolated.	Very low population densities with widely distributed villages with little or no inhabitants in between.	
2	Subscriber capacity	10,000	1000	200
3	Subscriber Voice MOU (outgoing)	50 minutes per month	50 minutes per month	50 minutes per month
4	Site voice Traffic (max of outgoing, incoming)	500,000 minutes per month	50,000 minutes per month	10,000 minutes per month
5	ARPU	\$5	\$2	\$2
6	Data throughput 2G/3G/4G	Up to 1Mbps/3Mbps	Up to 1Mbps/3Mbps	50kbps up to 1Mbps
7	Coverage Radius	15 - 45 km	~3 km	1-3 km
8	Optional Radio Technologies	L800, GU900	L800, GU900	GU900
9	Site availability	>= 98%	>= 95%	>= 95%
10	Dropped call rate	<1%	<3%	<5%
11	Site power	Solar Power with Battery Backup	Solar Power with Battery Backup	Solar Power with Battery Backup
12	Site autonomy	24 hours	24 hours	24 hours

Table 2 : Rural segmentation

This table does not state how far these underserved areas are from existing 2G network coverage. But construction of new sites may be a major concern since the major costs of a whole network reside here.

Therefore, another rural segmentation is proposed hereafter, introducing further classification of the spatial distribution of the villages and population in the relevant area. Essentially, the uncovered population is segmented thanks to indicators important for the network coverage: population in the village/area, distance of the village to existing network point of presence (PoP) and distance intervillages. Although, exact results may differ from one country to another,

It is noted that such segmentation is based on a geo-marketing case study (Orange internal) that has recently been developed in Niger. In this context (from a study achieved in 2016), there were 2,746,820 people who lived in uncovered villages having more than 300 inhabitants. But notice that results may differ from one country to another.



Number of villages per population range

Number of villages per distance to network range

Figure 1 : Statistics on number of villages (Niger case study – Orange)

Some average indicators per uncovered village:

Average village population	370 inhab.
Average distance to existing Orange Network	33 km
Average distance to neighbor village	3 km

From those population statistics, the underserved areas to be covered can be segmented in typical use cases as follows (see **Table 3**):

- Isolated small villages (segment 1) and isolated large villages (segment 2),
- Groups of gathered villages (segments 3, 3bis, 3ter) and spread villages (segment 4),

The criteria are detailed in Table 2Table 3. They extend the indicators given in Table 2 and define each segment according to a specific threshold value per indicator. Such criteria allow considering the major technical constraints in mobile radio access network, core infrastructure and backhaul, based on existing solutions. Coverage radius and surface area thresholds hereafter are defined according to current technologies: 3km radius for small cells, 20km for macro cells. Similarly, distance to PoP threshold (30km) is set according to microwave link range.

Segment	Number of villages	Coverage radius (km)	Surface area (km ²)	Population area (h)	Distance PoP (km)	Comment
Segment 1	1	3	30	<1 000	>30	Isolated small village
Segment 2	1	3	30	>=1 000	>30	Isolated large village
Segment 3	>1	20	1 250	>5 000	<=30	Group of high populated gathered villages relatively close to network
Segment 3bis	>1	20	1 250	>5 000	>30	Group of high populated gathered villages far from network
Segment 3ter	>1	20	1 250	3 000 to 5 000	<=30	Group of medium populated gathered villages relatively close to network
Segment 4	>1	>20	>1 250	N/A	N/A	Group of spread villages (all other cases)

Table 3: Rural segmentation with classification of spatial distribution of villages and population

It is observed that the highest potential market is Segment 3 (Group of high populated gathered villages relatively closed to network): despite the large coverage area, it comprises groups of gathered villages of more than 5 000 inhab. which are located at less than 30 km from an existing network.

The results of rural segments mapping with unconnected areas in Niger are summarized in Figure 2

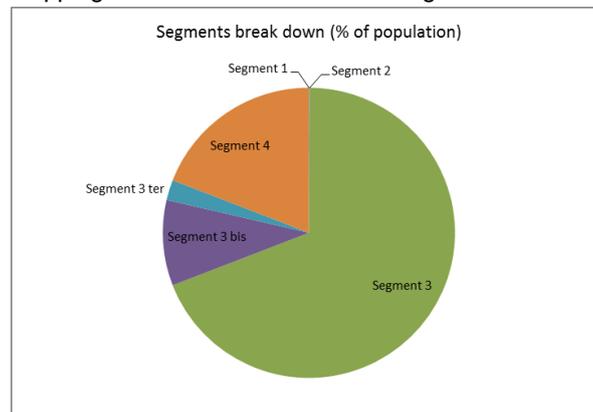


Figure 2: Segments distribution in Niger unconnected areas

From Figure 2, the following observations can be made:

- The segments 1 & 2 with very small coverage (3 km radius) are very limited in Niger. But it can exist in other MEA countries.
- The segment 3 with standard coverage (around 20 km) is the main potential in Niger as it addresses 80% of the uncovered population in Niger.
- The segment 4 represents the spread villages. It addresses nearly 20% of the uncovered population. For this segment, the highest the network coverage, the better.

Finally, enriched rural segmentation described in this subsection can help to derive network design options that are adequate for each identified segment. From various segmentation inputs given below, we can figure out that:

- In areas situated at few km from existing coverage (up to 45km):
 - co-located villages in rural areas situated at the border of existing coverage would benefit from large cell radius range because no new site would be required to provide minimal connectivity there.
 - In a second step, more capacities may be provided there thanks to technologies that get rid of building high sites required by microwave backhaul (line of sight). Such technologies may be based on relay techniques for instance.
- In areas situated far from existing coverage:
 - groups of numerous villages would also benefit from large cell radius as it will reduce the number of new sites required isolated big villages (> 1000 inhab.) may benefit from small cells backhauled by satellite in order to get rid of costs related to civil works for setting up microwave or fiber links
 - small isolated villages may benefit from direct satellite connectivity; of course the advantage of satellite is to provide connectivity at country scale without requiring any terrestrial deployment.
 - Coverage continuity between isolated villages (small, big or groups) may be provided by direct satellite connectivity. It can also be improved in some cases with larger cell radius from existing terrestrial infrastructures.

Extended coverage techniques, relaying solutions, satellite backhaul and access, are network design techniques identified by NGMN that are key priorities for rural connectivity and needs to be further developed in the telecom industry. Section Fehler! Verweisquelle konnte nicht gefunden werden. tackles potential solutions for deep rural environments where NGMN can make an impact on telecom ecosystem.

2.4 Explicit interest for Extreme Coverage

A recent trend is to deploy small cells in a single box (e.g., Open Cellular project: <https://telecominfraproject.com/>) in order to reduce the cost of the passive infrastructure (site rent, tower/mast, energy consumption), but such approach would result in deploying as many sites as unserved villages.

On the other hand, Long Range Communications solutions, definitely empowers mobile operators to expand their coverage footprint because the main costs of a network reside in deploying and operating access sites (tower, energy power, travelling for maintenance).

2.4.1 Reinforcing existing sites for extending coverage

Increasing the cell range of existing sites may contribute to extend connectivity to the uncovered villages which are located not so far from the existing coverage areas.

An estimate of the potential gain in terms of population coverage by increasing the cell range of existing radio sites is given by Figure 4 for Niger by considering the current 2G network deployed in Niger as a starting point (Orange internal study).

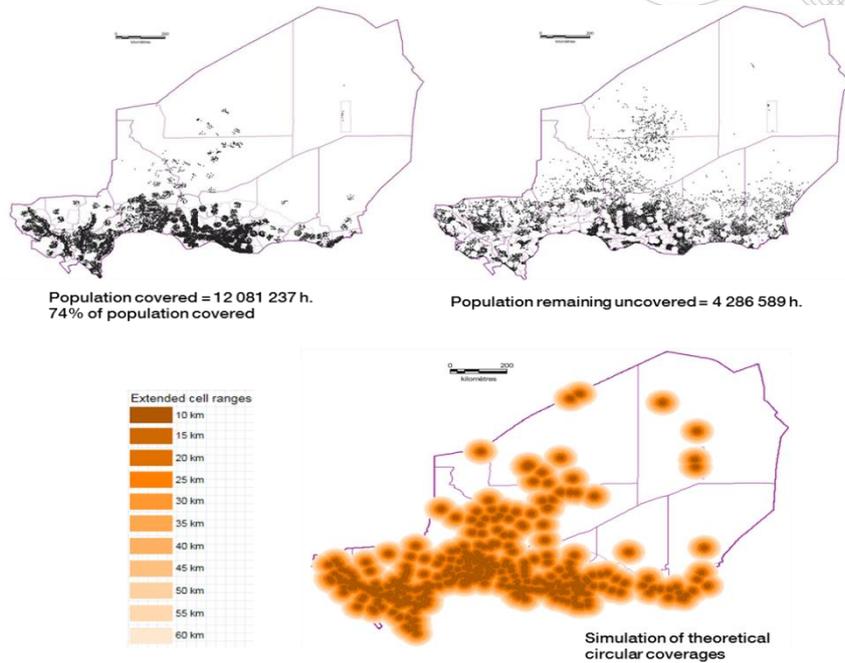


Figure 3: Coverage extension at country scale by extending range of existing sites in Niger (2019)

First, we assume an average theoretical circular cell range of 15 km for the coverage of existing 2G sites at the country level. From this existing coverage, approx. 75% of the population is covered. Second, the covered and uncovered population and localities are calculated and represented here in terms of population and localities values, as shown in Figure 4:

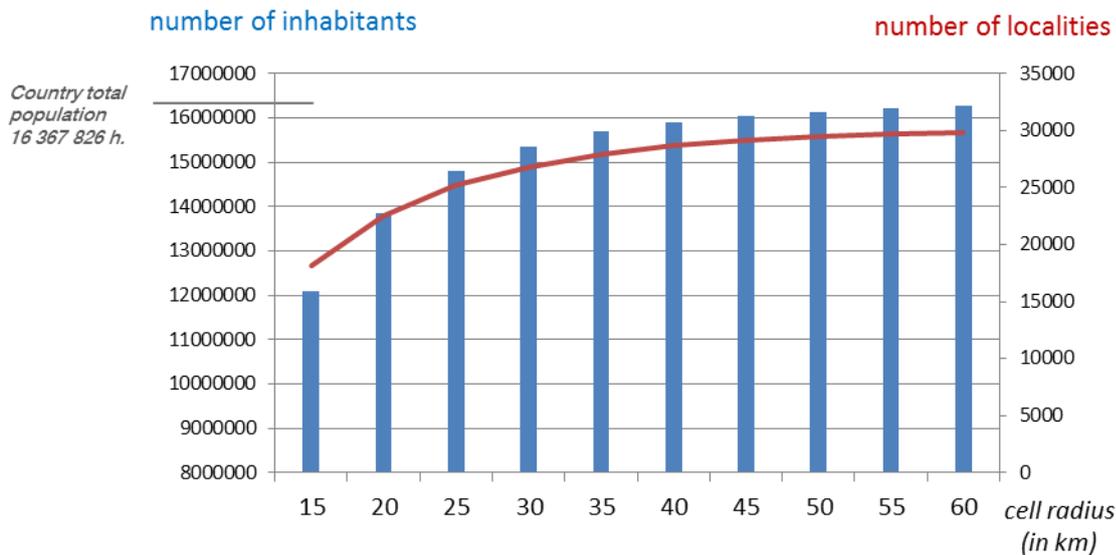


Figure 4: Fraction of population and localities under coverage function of cell radius

A raw estimation shows that with coverage extension techniques that would allow to extend cell radius from 15km to 30km, 95% of the total population would become covered (compared to 75% initially). Increasing further cell radius on existing sites would create high overlaps and undesired interference. So extending 50% of the existing sites up to 40 km radius would be enough to address 97% of the population.

We also can notice that gains beyond 45km cell radius are very low and that 100% of the population can't be achieved by extending only cell radius under realistic conditions (interference mitigation), e.g., extending coverage of a subset of cells only.

2.4.2 Building new sites for extending coverage

Increasing the cell range also enables to significantly reduce the number of sites to set up for extending the network coverage (both voice and data networks) at country level.

Figure 5 shows the impact of the cell radius for extending radio coverage, with a profitability criterion for deploying a new site being that it should cover at least 3000 inhabitants.

Assuming traditional deployments, theoretically 119 new sites would be necessary to extend the coverage to 60% of the uncovered villages having more than 300 inhabitants.

If radio technology improvements allow to reach a 45 km cell radius, a smaller number of sites (45) will be sufficient to cover a larger rate of villages (71%) since the profitability criteria (> 3000 inhab. per site) can be reached by the increased coverage.

If we consider 60 km cell radius, deploying only 33 new sites would cover 79% of villages having more than 300 inhabitants and 82% of population living in the uncovered areas.

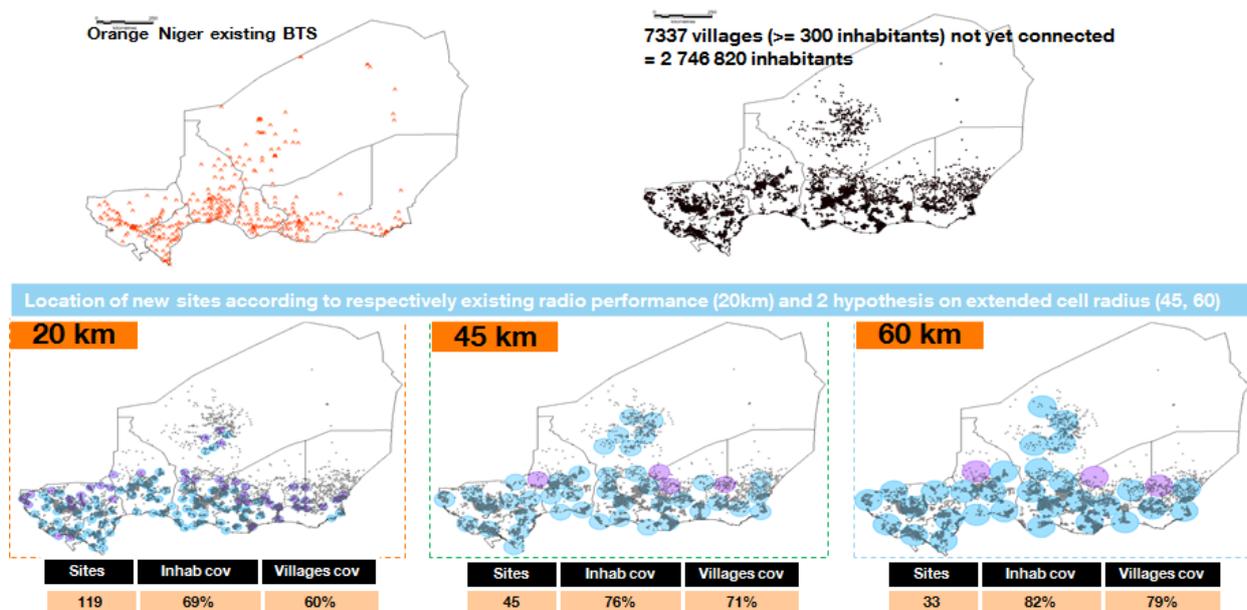


Figure 5: Coverage extension at country scale with new sites (e.g., Niger in 2016)

Results shown in sections 2.4.1 & 2.4.2 provide clear interest for long range cell solutions either by ability to extend existing coverage or by reducing the number of new sites needed to address underserved population. Figures for Niger were given as example and would of course differ from country to country due to population distribution and geography but the order of magnitude of increase in population coverage thanks to long range solutions should remain.

Potential solutions to expand cell radius and broaden coverage are discussed in Section 5. Among them cell coverage extension capabilities brought by LTE-M looks an interesting track. The trade-off would reside in reduced Quality of Service in extended areas. From a business perspective, connectivity may be provided in two steps:

- minimal services in a first step thanks to large cells,
- then adding more capacities thanks to more traditional technologies.



2.5 New business models

Beside technology improvement, low profitable areas should be addressed by new business models.

Infrastructure sharing or even network sharing is attractive for reducing costs and risks but can't face poor revenues. According to GSMA in 2017, most wholesale open-access networks initiatives for connecting the underserved have failed (Kenya, Russia, Mexico) [6], but there was one network rolled out successfully (Rwanda); such model is currently also applied in Turkey.

New actors, notably IPX Extenso or Africa Mobile Networks, have initiated some deployments based on revenue sharing with MNO. The solution may suit remote villages far from existing networks. The technical solution is based on small cells backhauled by satellite owned by these actors who build the site; radio access spectrum is owned by the MNO. Revenue sharing is based on accounting the link between satellite gateway (or satellite ground segment) and MNO core network. This requires a community of local agents for operating the access networks (L1 and L2 operations) as well as marketing activities (e.g., selling sim cards). These actors may also increase their revenues by selling electricity (solar power stations). The solution is currently limited to voice services. Data service would require lower backhaul costs.

Whatever the technology and the model of sharing, profitability in underserved areas is hardly reached without sponsoring. But sponsoring building infrastructure is costly and MNOs have to cover operational costs. Moreover it does not distinguish clients who can afford to pay for connectivity and those who can't. The first model has been proposed from 2013 by the sponsoring of Turkish Republic Ministry of Transport and Infrastructure and managed by Turkcell Turkey. In this Project, for meeting the costs the "Net Cost Regulation" were executed. In this regulation, net costs are calculated by the extraction of network revenues from the total of network rollout and operating expenses. A new model was proposed in 2017 by the Indian government in response to its decision to block Facebook Free Basic (because it was not fair enough between service providers). This new model consists in sponsoring the traffic that the poorest population can't afford under a certain threshold. Technically, it could be based on data reward principle. The core network may filter the traffic from a set of end-users and charge the sponsor instead of these clients.

3 OPERATORS REQUIREMENTS FOR RURAL

Coverage has historically been the main challenge for rural cellular in mature markets, and any increase in the maximum coupling loss (MCL) for a service increases its coverage and usability in rural areas. The geography of rural access is far more varied than urban geography, with fjords, mountains, islands, ice, deserts, weather extremes and vast distances posing unique challenges to radio coverage, backhaul and power availability, and site construction and maintenance. In some areas, mountains are so high or distances so vast that wide-area coverage is only likely to be possible from aerial or satellite platforms. Though the technological solutions are still emerging, there are compelling reasons for which operators would like to provide wide area coverage even where population densities are low and geography is challenging:

- Wide area connectivity provides a public safety benefit
- There is user interest and a marketing advantage to having wider coverage – users wish to be always covered
- Wide coverage expands the addressable market for services
- Wide coverage technologies can allow an operator to divert other infrastructure spend away from achieving coverage and towards meeting capacity demand



To effectively expand coverage, operators need long-reach (ie, high MCL) radio solutions, rugged and cost-effective backhaul and off-grid power options, and affordable means to increase base-station height to overcome terrain and Earth curvature. **In areas where coverage is the most important criteria, achieving the highest cell radius is of paramount importance for macro sites to maximize geographical coverage and traffic uptake. All features that allow further coverage extension are interesting and should be considered.** 100 km cell radius is defined in 3GPP TR 38.913 [7] as target for “Extreme long distance coverage in low density areas” scenario. Of course, the cell radius is a combination of different parameters like site height, output power and more specifically Effective Isotropic Radiated Power (EIRP), environment type, number of transmitter and receiver antennas, propagation characteristics... The site height is the most straightforward parameter on which operator can play with but is also the most expensive (ranging from 25% to 50% of the total site price). **For this reason, RAN and chipset vendors are encouraged to provide software features that enable coverage extensions. A smooth integration of direct access spatial solutions within the existing terrestrial mobile networks look also like a promising option to provide large nationwide coverage.** This will be further developed in Chapter 5.3.

Deep rural environments are diverse among markets with different characteristics that need to be taken into account by MNOs for their mobile networks roll out. For instance deployment constraints and strategies will be different for a North American operator that targets wide rural areas with low population density spread in villages interconnected with roads. This is high ARPU market but customer expectations would be the same as elsewhere in the network. On the other hand Sub-Saharan operators face the challenge to provide wide coverage in far remote rural areas to poor and often illiterate population. Customers’ Quality of Service expectations are generally lower in those underserved markets than in more mature markets.

Whatever countries development, rural markets are everywhere and every MNO are facing this challenge. Operators in low ARPU emerging markets mainly in Africa, Latin America and Asia will have some specific requirements. Operators in higher ARPU markets (e.g. North American) will also have their own specificities.

3.1 Low ARPU emerging markets

In emerging markets, population coverage ratio reaches on average 90% for 2G voice services (see Section 2). This average value hides large disparities in service availability in far remote regions. Moreover access to Internet connection through 3G or 4G mobile networks is generally available in urban and suburban areas but rural and far remote rural areas are often forgotten. Rural areas are generally considered and studied thanks to profitability levels that operators can expect. It has to be noted that rural coverage is sometimes encouraged (and even mandatory in some countries) by regulators as long as minimal profitability can be reached. The usual strategy for choosing rural areas to be covered is based on existing coverage (one more microwave backhaul hop and backbone capacity) and the expected profitability (e.g. population density in the area and economical activities). Several geo-marketing segments are usually considered: the number of villages that can be covered by a new cell, the population in these villages, the distance between villages, and the distance to the existing coverage. From this, rural areas with several gathered big villages are generally already covered in 2G or ranked as priority for their potential. On the other hand, rural areas with lower population and/or widespread villages are then considered with lower priorities due to their lower profitability levels.

Access to data services is far less developed in rural areas in emerging countries than access to voice services. Mobile network operators (MNO) have various strategies with respect to technologies for data provision. On one hand, some operators have deployed 3G in urban areas for some time and continue to progressively expand their coverage in rural areas on 3G also. Those operators are generally at the very beginning of 4G roll out especially in rural environments but the trend is to accelerate on 4G deployments. On the other hand, some operators might not have access to 3G spectrum and go directly to 4G with a strategy on low cost 4G end-user devices. Operator like Jio Reliance in India skipped 3G technology for data and moved very fast on 4G deployment to provide the



maximum population coverage with disruptive commercial offers (GSMA Report – Asia Pacific 2018) [8]. But the possibility to apply this strategy to other countries relies on the spectrum regulation, and needs to be carried on with a strategy on 4G end-user devices

GSMA regional reports [9] are good highlights on market trends.

As for voice service delivery, site deployment opportunities for data service are assessed with operator profitability levels based on potential population penetration and expected ARPU. When an existing 2G site is upgraded to 3G or 4G (or both) to provide data services, main cost item resides in backhaul dimensioning to sustain data traffic increase.

Consequently smart rural market segmentation is key for operators to deploy efficiently their networks. This is enabled only by excellent knowledge of local population localization and number of inhabitants. Census and local knowledge are prime source of information. New geomarketing tools based on satellite imagery with claimed Artificial Intelligence (AI) capabilities are emerging with the promise to derive automatically population localization and amount. MNOs also face some challenges that still need to be met, such as to deal with areas with migrating population in order to avoid to deploy a site somewhere and to get no user because they have moved in the meantime.

One of the first operator requirements to enable efficient rural market segmentations (cf. Section Fehler! Verweisquelle konnte nicht gefunden werden.) to decide where to deploy rural sites is access to recent and accurate population data and smart geomarketing tool access.

New quality of service criteria should be defined for minimal service provision, enabling to reach profitability in areas where traditional services do not reach profitability while still meeting satisfaction from users. These criteria may impact or not the number of dropped calls, voice quality... Typically, it is already the case with the use of half rate codecs in GSM, where the quality of voice is degraded but still acceptable. Criteria that should not be relaxed must be identified, such as network availability due to support of emergency services. Finally, notice that the level of service should be adapted to the rural market segment and not used for reducing network costs where better service quality can be provided. Competition between operators is a key factor to prevent an operator to reduce service quality.

A tradeoff between no coverage and top rated quality of service can be found that allow MNOs to deploy their networks in a sustainable economical way. Newly connected users in far remote rural of emerging countries may be more tolerant to dropped calls, moderate voice quality and network unavailability than customers in urban areas. Targets for operational KPIs like Dropped Calls Rate, Experienced Data Rate, Network Unavailability Rate, Voice Mean Opinion Score depends on each and every operator rural strategy but are generally less stringent than for urban areas. Accurate rural market segmentation is also a mean to set Quality of Service (QoS) targets for various rural segments with adequate options for roll-out. Rural segments are generally defined according to population density and topology with for instance “Rural” segment to be covered by large macro sites and “Ultra Rural” segment with medium macro sites, or “Rural with gathered villages” and “Rural with widespread villages” each with specific deployment strategy... QoS target relaxation allows MNOs to use optimum profitable equipment to deploy their networks. Good illustrations are solar powered sites with less autonomy, low cost site infrastructure (no concrete, light poles...), minimal traffic capacity per site (TRX numbers, output power...).

Access to energy is also challenging in far remote areas with sometimes unstable electric grids. Solar power is generally the preferred choice when access to electric grid is not available. Diesel is an option in regions where sun exposition does not allow solar power. **Site solutions that lower energy consumption and improve site autonomy are favored. RAN vendors are encouraged to provide innovative sleep modes management features** that can cope with “Network Unavailability” KPI target relaxation (see above).



3.2 Higher ARPU markets

While increasing revenue per subscriber can help to improve the business case for expanding coverage, the challenges to building coverage posed by terrain, climate, distance, and low population density remain challenging in many high ARPU markets – and the service expectations are generally higher. Rural residents value digital access to government and health services, shopping, entertainment, education, workplaces, friends, and family more highly than their urban counterparts. Governments recognize the value of rural connectivity, and some have introduced subsidies or service requirements to encourage coverage and capacity increases. To meet rural connectivity needs, many operators are using mobile networks to provide rural fixed internet service, increasing both the revenue generated by these rural wireless networks on one hand, and the demand placed on them on the other hand.

As residents have access to mid or high-end smartphones and fixed-access user-equipment, operators who are upgrading or deploying new network equipment are motivated to support higher 3GPP releases and features to improve latency, peak rate, system capacity, and service support. Where operators offer fixed wireless Internet service, rural system capacity becomes a primary concern, and operators require high speed solutions.

In contrast to emerging markets, in more mature telecom markets wired telephony may be common even in very small and remote communities, and good demographic and other planning information is usually available from a variety of sources.

4 DEPLOYMENT GUIDELINES

This section highlights operators Best Practice for deploying networks in deep rural environments as well as challenges they are facing.

4.1 Solving the lack of reliable population data

First step for operators who deploy mobile networks is to identify where population lives and where to deploy telecommunication equipment. In mature markets this is quite straight forward as population location is generally well known [10]. But in emerging markets with sometimes nomadic population this becomes a challenge. Lack of reliable data population is an obstacle on site planning and deployment for most of MNOs. Population census, Offices of National Statistics [11] and local knowledge are main traditional source of information coupled with accurate propagation model to identify underserved areas and amount of uncovered population. Innovative solutions are emerging based on satellite imagery. Artificial Intelligence is used to identify and count households and group them into settlements. Models trained with data census improve accuracy of automatic satellite population detection. Coupled with coverage map of existing networks, geolocation of undeserved population are then identified. GSMA supports those innovative approaches by providing Mobile Coverage Maps platform developed within its Connected Society Program [12].

4.2 Backhauling options

Backhaul architectures in deep rural region are often dictated by existing infrastructures. Operators use optical fiber where it is already available but generally won't deploy new fiber links for remote villages due to prohibitive costs. Microwave links are the preferred options when first network Point of Presence (PoP) is reachable. Costs, easiness of deployment and products maturity are the main reason of microwave adoption. RAN equipment in remote regions that cannot be reached even with multiple hops of microwave links are generally connected to operators Core Networks through satellite links using VSAT (Very Small Aperture Terminal). Annex in [9] and [10] presents scenario where the backhaul between various RAN and Core elements are routed through a GEO Satellite Link.



The presented solutions cover UMTS and LTE Network Technologies and provide a number of deployment variations to illustrate alternative deployment options for remote and isolated areas where investment in backhaul is unviable and/or impractical. In the first instance, signalling elements, which inherently have low traffic volume, can be implemented remote to the Site and over the satellite links and in some cases non-live internet traffic can be cached locally. However, in all scenarios presented, and with growing demand for high speed data, it is inevitable that some live internet data has to be routed over the satellite links; this makes supplying data to these remote sites very expensive particularly if expensive GEO Satellite links are used. In order to reach a compromise and balance architectural solutions, the user traffic model must first be analysed and based on the internet data usage a suitable variant implemented. Alternative solution to microwave links and satellites could be fixed wireless with smart beamforming operating at lower frequency bands. The 5G NR IAB solutions is a good example and although IAB for NR has been studied for below and above 6 GHz, the sub-6GHz case would be clearly beneficial. This is further developed in Section 5.2. In extreme cases like very low-density or challenging areas disruptive flying networks solutions can be used. Google Loons are a technology that proved its ability to provide RAN and / or transport in highly complex areas.

4.3 Rural sites design

Deep rural site configurations generally consist in using geography to maximize coverage by use of high points and open areas. Adequate site location combined with use of low frequency bands below 1 GHz allows maximum range communications. No predetermined rural site design exists among operators. Mast height and associated civil works, antenna type (tri-sector, omnidirectional), telecom equipment family (high power macro cells to microcells) are determined by population and traffic volume to serve and expected site ROI. Power grids are sometimes unavailable and often not stable enough to be used to supply telecom equipment. Therefore in regions with enough sun exposure, solar panels are used as primary power source. Diesel generators are alternatives to solar panels in cold remote regions (eg. north Canada). Radio sites designed for rural with integrated relaying capabilities are of high interest for operators in underserved areas.

4.3.1 Lightweight sites with integrated backhaul – Ghana case study

GSMA Rural connectivity innovation case study [13] described solutions with integrated access and backhaul solutions as promising solutions for Sub-Saharan African areas. This case study shows that one of the key issues in bringing mobile coverage to rural areas, in particular in developing markets, is the higher cost of provision compared to urban areas. This higher cost is mainly due to three factors on:

- Tower and civil works. Installing and maintaining a cell site in rural areas can be costly due to the lack of infrastructure, roads for instance. In addition rural locations are often more prone to political or security issues
- Backhaul: Fiber backhaul is normally not available, and it may not be feasible to use a microwave network to cover long distances. This means that satellite backhaul could be needed, which adds significantly to the operating costs.
- Power: Remote areas may not have access to the grid, in which case alternative power sources – such as diesel generators – will be needed. These are more costly and require regular maintenance

There are alternatives to the traditional macro-cell networks that lower the costs above in certain scenarios. Macro cells capable of a range of 10 km or more are suitable for areas with high population density and where continuous coverage is required, but they are not well suited to rural areas with small, scarcely distributed villages and with low population density. Those scenarios are better served with small, lightweight cells that target specific isolated settlements.

Recent lightweight solutions, such as Huawei Ruralstar, are based on a number of technical innovations that make them cost effective in rural scenarios with low population density. These innovations are

- Wireless backhaul: instead of satellite or microwave backhaul, lightweight sites backhaul via a cellular relay operating in one of the existing mobile bands. This allows for non-line-of-sight links of 10-40km from a donor BSs.
- Low power consumption, made possible by modern power amplifiers which require 200-300W only. The site can thereby rely on solar panels instead of diesel generators.
- Small footprint. Lightweight sites are designed for coverage ranges of 2-4 km and thus do not require high towers. In addition, their overall physical size and weight are smaller than traditional sites. This means that the base station can be built on guyed poles and with reduced footprint (6sqm), removing the need for concrete foundations
- Multihop: Modern lightweight installations can extend their reach through added 'hops' between sites from the donor site. A typical installation would be one where the donor site is on a high tower. A first NLOS on a low frequency band could achieve a separation of 10-40km. From there, multi-hops to additional lightweight sites are possible, reaching 5-10km each between the sites. As a result, the reach of the wireless backhaul link from the donor site can be extended to 60km. This is shown in the figure below:

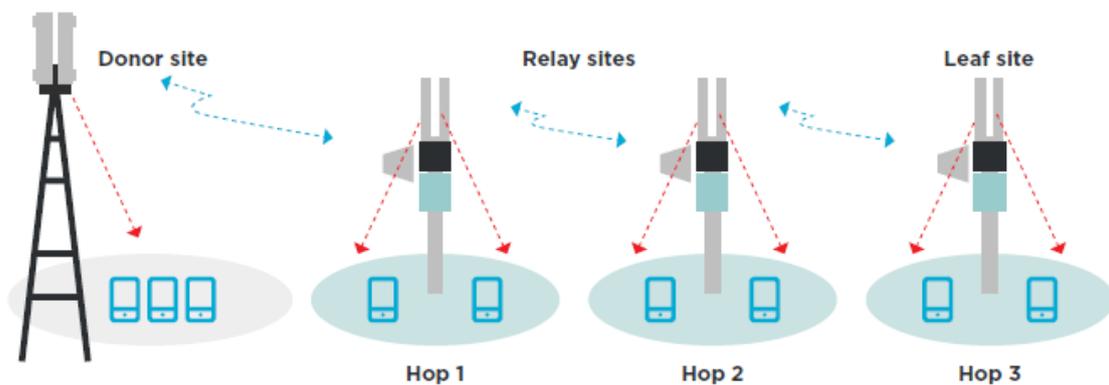


Figure 6: **Multihop lightweight deployment (source: GSMA)**

Lightweight sites can offer mobile operators a cost efficient solution for rural areas in emerging markets or developed markets. According to GSMA’s estimations, the total cost of ownership over the first 5 years can be a fourth of the cost of a macrosite.

	CapEx	OpEx	5-year TCO	Range
Typical Macro	100%	100%	100%	8-10 km
Lightweight	31%	14%	23%	3-5 km

Table 4: Cost and coverage comparison of a lightweight site relative to a typical macro-site (source: GSMA)

MTN in Ghana has deployed a few hundreds of lightweight sites from Huawei. The GSMA study of the Ghana deployments concludes that these solutions operators are able to improve rural coverage quality and reach areas that traditional macro-sites would not be able to cover in a commercially sustainable manner. In combination with careful site location analysis, light sites can be an attractive solution for operators to increase coverage and revenues in rural areas and extend mobile internet access to underserved populations

4.4 Multi Operator Radio Access Network Sharing - Turkcell case study

In 2013, Republic of Turkey's Ministry of Transport and Infrastructure announced a tender for rural areas where the population is less than 500 dwellers and have no mobile coverage. The motivation of this tender was based on the Turkish Constitution in which emphasized that "Anybody living in the territory of Republic of Turkey, without any discrimination on the basis of region and place of residence, shall avail himself/herself of the electronic communications services". All three Mobile Operators of Turkey participated in that tender won by Turkcell. Project costs were sponsored by Turkish Republic Ministry of Transport and Infrastructure based on the Law of Universal Service.

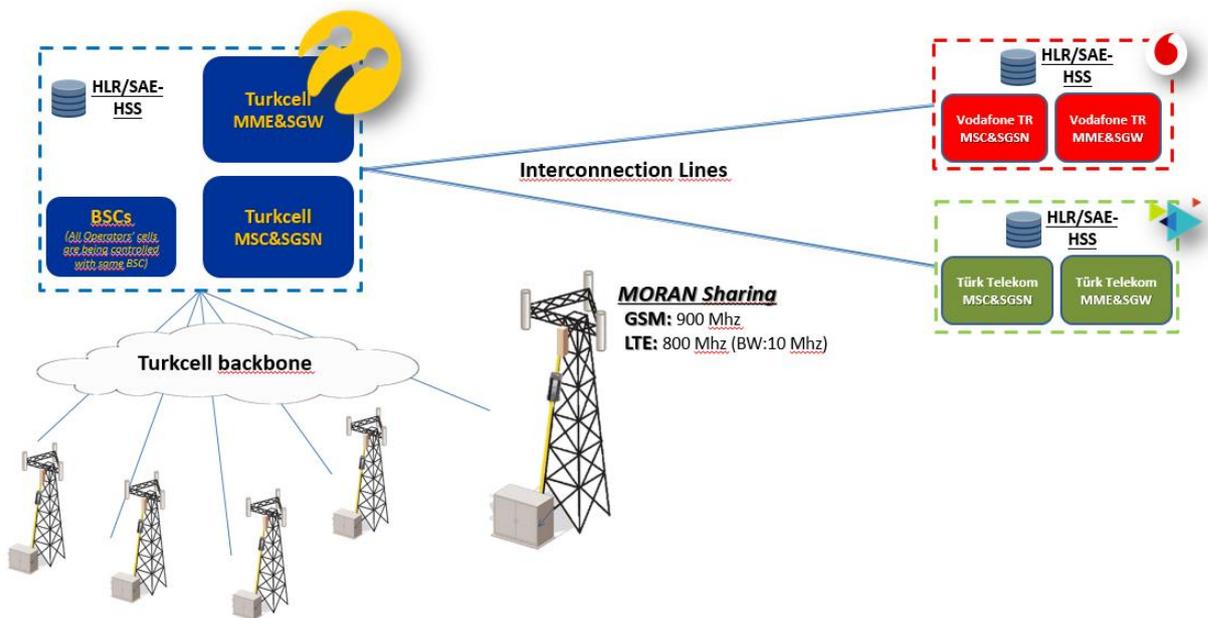


Figure 7: MORAN architecture

MORAN (Multi Operator Radio Access Network) Sharing was preferred by three Turkish operators which are Turkcell, Vodafone Turkey and Turk Telekom for both GSM and LTE Networks. All Operators' cells use the same antennas, same radio units, same base band units, same transmission lines and same base station controllers. Core network equipment such as Mobile Switching Center (MSC), Media GateWay (MGW), Mobility Management Entity (MME), Serving GPRS Support Node (SGSN) are separated. Deployment, operation and maintenance of these core network and radio access nodes are under Turkcell's responsibility. Only Home Location Register (HLR) and Home Subscriber Server (HSS) equipment are operator specific of information security concern.

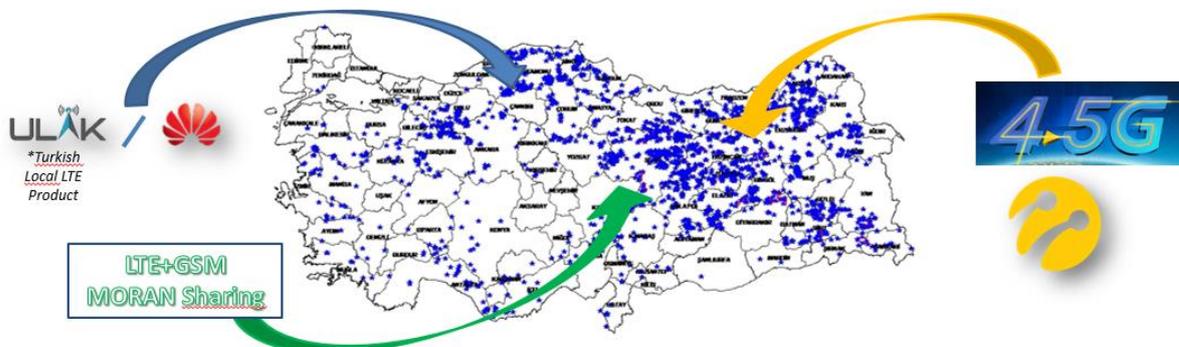


Figure 8: Turkish national coverage program



Turkcell covered 258.000 population in 1799 villages with 1146 GSM sites between 2013 and 2016. As a second phase, all these 1799 villages were covered with LTE until the end of 2018.

5 SOLUTIONS ON WHICH NGMN CAN MAKE AN IMPACT

Section 4 described operators' processes and solutions to cope with deep rural environments specificities. It highlights lacks of specific and tailored solutions to address those markets. NGMN is not the only organization to share this observation. Among other, EU funded research project ONE5G [14] is tackling specifically underserved areas. Through this paper, NGMN would like to encourage the telecom industry to develop extreme long range solutions that match operators' needs in deep rural environments.

Potential long range solutions on which NGMN expects development span the whole telecommunication chain from new device capabilities, tailored access and backhaul products and new spatial access type solutions.

5.1 Smartphones with Coverage Extension capabilities

Smartphones coverage could be extended by re-using coverage enhancements capabilities defined for Cat-M UE's. The idea would be to benefit from Coverage Enhancement (CE) techniques defined for Cat-M but keep advantages of traditional UE Category (from Cat1 to Cat6 and higher).

This new type of UE would then be non-Bandwidth Limited (non-BL) and would support all LTE bandwidths (1.4/5/10/15/20 MHz) with peak throughput corresponding to its LTE UE Category which is much higher than LTE-M UEs (Cat-M1 is limited to 1,4MHz BW, Cat-M2 to 5MHz). They would also support full mobility and QoS procedures. Their great advantage would be that on top of this, they would support Coverage Enhancement capability: Mode A for 3GPP Rel.13 or Mode A&B for 3GPP Rel.14 UEs.

From 3GPP standpoint no new UE Category would be needed to support this new UE type. A traditional UE Category (from Cat1 to Cat6 and higher) would declare the following UE capabilities as defined in TR36.306 [15]

- ce-ModeA-r13 and ce-ModeB-r13 : to define whether the UE supports operation in coverage enhancements in Mode A or B
- intraFreqA3-CE-ModeA-r13 and intraFreqA3-CE-ModeB-r13 to support of event A3 to switch between normal coverage mode and coverage extension mode.

Those parameters are mandatory for UE CatM1 but are exclusive and could be defined for other UE Categories.

Mobility management between coverage modes are not expected to be specified by 3GPP and would rely on proprietary implementations (event triggered, RSRP thresholds...). Those new dual mode UEs scheduling would perform according to their working mode (enhanced coverage or normal coverage). System Information of both coverage modes should be broadcast and dual mode UEs will listen according to its current working mode. Paging, Cell selection and reselection procedures could be adapted by proprietary implementations to manage the support of 2 coverage modes, but could also benefit from 3GPP standardized procedures.

From a 3GPP standpoint VoLTE is supported for non-BL UEs with CE capabilities nevertheless voice QoS with signal repetitions needs to be assessed as it might appear unacceptable for customers.

Text and RCS messaging would see improved availability and reach through CE.

NGMN encourages chipset and smartphone vendors to adopt this approach. Development of relevant products is of course not straightforward and technical questions related to call establishments, mobility between normal coverage to extended coverage areas and other paging mechanisms should be tackled with involvement of RAN vendors. Operators inside NGMN are ready to help define and review product specifications.

Those smartphones with coverage extension capabilities would come with a trade-off in reduced Quality of Service or functionality in extended areas. From a business perspective, in addition to providing service continuity,

extended reach can be used to build a customer base on a basic service to nurture the demand required to support investments in capacity.

5.2 Wider development of relaying solutions for access & backhaul

Section 4 highlights both the lack of dedicated rural site designs and difficulties linked to backhaul solutions. Operators generally build their site design for deep rural areas by imbricating products that ranges from masts, BBU, RRU, Backhaul, power, antennas that in the end do not fit rural specificities in terms of costs, coverage, easiness of deployment, security, maintenance... Most of vendors' portfolios are designed for profitable urban environments but lack of integrated products specifically developed for rural environments.

In particular 3GPP specified LTE relaying solutions [16] (3GPP TR 36.826) and NR Integrated Access and Backhaul 3GPP TR 38.874 [17] that would enable to get rid of some backhauling limitations and difficulties especially in deep rural environments. Networks with relay nodes (RN) are designed to extend coverage and increase throughputs in areas with poor performances.

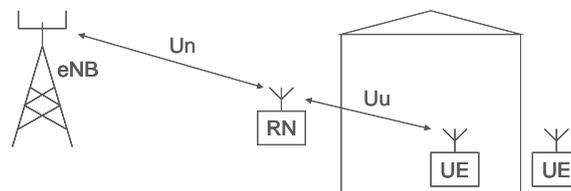


Figure 9: Example of a relay deployment scenario – TR36.826

Access and Backhaul is a new approach whereby the NR/5G Frequency band is used for backhauling from remote sites back to an aggregation point. Products with integrated access and backhaul solutions, should it be inband (shared frequency band between UEs and relays) or outband solutions (separate bands between UEs and relays), would ease site deployments in regions where Network Point of Presence (PoP) is hard to reach due to distances. Access to energy to power telecom equipment is also often tricky in regions where grid is sometimes unstable. Diesel or solar panels are the widest used solutions to overcome grid shortage with all their inherent limitations to power high consuming equipment.

To efficiently address those challenges, **NGMN would request vendors to enlarge their portfolios with integrated “all in one” rural site products specifically designed for deep rural environments.** Those lines of products would ideally encompass integrated access and backhaul relaying capabilities, low power consumption telecom equipment with integrated solar panels for regions with enough sun exposure, large choice of passive infrastructures ranging from easy to deploy masts to high towers. Ghana case study presented in Section 4.3.1 is a nice example of use of relaying products tailored for rural environments. Such solution would benefit from a wider amount of supported technologies (3G, 4G) and features (multiple hops...). Such products would favor sustainable and efficient network roll out in extreme rural environments.

5.3 Non-Terrestrial Network solutions

The Non-Terrestrial Network (NTN) terminology, as used within 3GPP, covers both the concepts of airborne platforms and telecommunications satellites.

For aerial communications, altitudes of 8-50 km are here considered. In practice, in the NTN documents studied so far at 3GPP, airborne platforms rather refer to high altitude platforms (HAPs), generally evolving in the low stratosphere, at altitudes in the range 17-25 km. Such airborne platforms represent a new alternative to terrestrial and satellite communication systems for a large set of applications including the provisioning of wireless broadband. They have attracted a significant interest during the recent years due to their unique features, together with the relatively easy deployment and maintenance aspects. HAPs are hence well-suited to support



telecommunication services, due to their rapid deployment time. Moreover, when applicable, their propulsive capabilities could be used to move the platform where it is best needed, without any prior need to ground the HAP. Also, the use of smart antennas, with highly adaptive beams, is likely to enhance the offered performance. Several large organizations, startups and more traditional actors from the aerospace industry have initiated HAP development programs, and companies such as Alphabet (Loons), Airbus (Zephyr) and Thales (Stratobus) are targeting prototyping, experimentation and production phases. The availability of commercial products is generally scheduled around 2020-2022.

As for space-based communications, satellites are indeed currently undergoing major evolutions, which are likely to significantly impact the whole telecommunications domain. How these evolutions will exert an influence on MNOs is yet to be fully assessed. Will these advances mainly trigger an improvement of the services traditionally provided by existing geostationary (GEO) satellites, for instance in the context of maritime, railway and airborne services, or can a stronger convergence with terrestrial networks, notably in the context of 5G, can also be anticipated? That is one of the main questions the ongoing NTN studies at 3GPP intend to address, both in the context of HAP and traditional GEO satellites, but also with respect to the new generations of non-geostationary orbiting satellites (NGSO) which notably encompass low and medium earth orbiting (respectively LEO and MEO satellites). Several NGSO satellite initiatives have recently been announced, and for some of them, deployed. That is notably the case of the MEO O3b fleet, or of planned LEO satellite constellations from actors like OneWeb, SpaceX and LeoSat, for instance. These projects offer disruptive approaches and perspectives, notably in terms of lower latency and cost cutbacks. Regarding the upcoming generations of NGSO constellations, which are targeted to be commercially launched in phases, in the 2020-2025 timeframe, MNOs expect an increase in backhaul capacity offer thanks to high satellites number with smart beamforming antennas, together with lower signal latency enabled by lower altitudes of operations (about 500-2000 km for LEOs and 8000-20000 km for MEOs).

Regarding NTN connectivity costs, recent advances allow anticipating a significant decrease in the years ahead. For instance, the generalization of high throughput (HTS) techniques enables better spectral efficiency and contributes to reduce the cost per bit delivered. Another example is the design of in-orbit reprogrammable features, as announced by Eutelsat with its Quantum satellites, which is intended to result in cheaper and faster satellite manufacturing methods by using generic subsystems and equipment. Even more significantly, it is expected that the new generation of NGSO constellations should strengthen that cost decrease trend. This improved cost efficiency is first explained by lower manufacturing prices per unit, since NGSO satellites are generally smaller, with less power requirements per satellite. Furthermore, the disruptive satellite production lines set up in place for constellations such as OneWeb and Starlink are expected to decrease manufacturing time and subsequent costs. Also, since life expectancy of a LEO satellite is set to 3-7 years (compared to 12-15 years for a GEO satellite), constraints on space electronics may be less stringent and in turn be supported more often by affordable consumer-grade (as opposed to space-grade) components. Regarding the launching costs, a given mass of LEO payload is inherently less expensive to put in orbit, compared to GEOs. Moreover, a whole new generation of launchers (SpaceX and its partially reusable launchers, Virgin Orbit, Vector Launch ...) should decrease further the kg of payload per dollar ratio. Nevertheless, these factors should at least be partially balanced with less favorable elements, such as the generally added complexity of NGSO architectures. The first commercial openings of prominent LEO constellations and HAP systems, around 2020 onwards, should help clarify NTN connectivity cost forecast.

Thanks to lower altitudes of operation and therefore lower propagation delays, NGSO satellites could also cope with direct access to the ground. For instance, representative one-way propagation delays for a LEO satellite orbiting at 600 km are around 15 ms, versus around 272 ms for GEO satellites, according to [1]. **This direct access capability would offer MNOs the means to provide wide coverage particularly in far remote rural areas that are not covered by terrestrial solutions.**

In this context, 3GPP started to develop SI on NR to support non-terrestrial networks (TR 38.811 [18] and TR 38.821 [19]) with definition of Non-Terrestrial Network (NTN) deployment scenario with options for smooth integration with terrestrial networks and identification of potentially affected NR features. As can be expected, target



use cases essentially focus on eMBB and mMTC, by illustrating cases of network deployments for unserved and ill-served areas, specific verticals like maritime, offshore or railways communications, services relying on broadcast, multicast and coverage ubiquity. Likewise, a major advantage of NTN networks is its ability to support flexible and fast network restoration cases, for instance in the context of public protection and disaster relief (PPDR).

In terms of architectural designs, these studies intend to focus on both transparent and non-transparent payload architectures. While in the first case, signals are redirected from the ground back to earth with frequency transposition, re-amplification and filtering only, in the second case, signals are also demodulated and decoded, thereby supporting various types of onboard processing. For instance, non-transparent architecture may allow the deployment of onboard gNodeBs as well as inter-platform links, with the benefit of potential performance improvements, but at the cost of increased design complexity. It should be noted that it could be a challenge to establish ground stations in some rural areas. Consequently inter-satellites links to carry backhaul information are seen as important architecture features in NTN solutions. Furthermore, the considered 3GPP studies mainly focus on two classes of terminals: very small aperture terminals (VSAT), and category-3 LTE UEs. On that basis, as shown by Figure 10, five deployment scenarios are considered: two pairs of scenarios for GEO and LEO (to take into account the specifics of each terminal class), plus one HAP-based scenario, which targets both terminal classes. While VSAT terminals mainly support use cases such as fixed and mobile cell connectivity, trunking, direct-to-node broadcast/multicast and redundancy services, category-3 UEs are envisioned to be used in the context of public safety, IoT and direct-to-mobile connectivity use cases. **It is worth highlighting that direct-to-node and direct-to-mobile solutions are of particular interest from the NGMN viewpoint to support deep rural coverage, both for direct access as well as seamless integration with existing terrestrial networks.** It is worth noting that for the satellite scenarios, two exemplary frequency bands are associated with each class of terminal: S-band (around 2GHz for UL and DL) for the category-3 UEs, Ka-band (around 20GHz for DL, 30 GHz for UL) for the VSATs.

Main attributes	Deployment-D1	Deployment-D2	Deployment-D3	Deployment-D4	Deployment-D5
Platform orbit and altitude	GEO at 35 786 km	GEO at 35 786 km	Non-GEO down to 600 km	Non-GEO down to 600 km	UAS between 8 km and 50 km including HAPS
Carrier Frequency on the link between Air / space-borne platform and UE	Around 20 GHz for DL Around 30 GHz for UL (Ka band)	Around 2 GHz for both DL and UL (S band)	Around 2 GHz for both DL and UL (S band)	Around 20 GHz for DL Around 30 GHz for UL (Ka band)	Below and above 6 GHz
Beam pattern	Earth fixed beams	Earth fixed beams	Moving beams	Earth fixed beams	Earth fixed beams
Duplexing	FDD	FDD	FDD	FDD	FDD
Channel Bandwidth (DL + UL)	Up to 2 * 800 MHz	Up to 2 * 20 MHz	Up to 2 * 20MHz	Up to 2 * 800 MHz	Up to 2 * 80 MHz in mobile use and 2 * 1800 MHz in fixed use
NTN architecture options (See clause 4)	A3	A1	A2	A4	A2
NTN Terminal type	Very Small Aperture Terminal (fixed or mounted on Moving Platforms) implementing a relay node	Up to 3GPP class 3 UE [2]	Up to 3GPP class 3 UE [2]	Very Small Aperture Terminal (fixed or mounted on Moving Platforms) implementing a Relay node	Up to 3GPP class 3 UE [2] Also Very Small Aperture Terminal
NTN terminal Distribution	100% Outdoors	100% Outdoors	100% Outdoors	100% Outdoors	Indoor and Outdoor
NTN terminal Speed	up to 1000 km/h (e.g. aircraft)	up to 1000 km/h (e.g. aircraft)	up to 1000 km/h (e.g. aircraft)	up to 1000 km/h (e.g. aircraft)	up to 500 km/h (e.g. high speed trains)
Main rationales	GEO based indirect access via relay node	GEO based direct access	Non-GEO based direct access	Non-GEO based indirect access via relay node	Support of low latency services for 3GPP mobile UEs, both indoors and outdoors
Supported Uses cases, see clause 4	1/ eMBB: multi-connectivity, fixed cell connectivity, mobile cell connectivity, network resilience, Trunking, edge network delivery, Mobile cell hybrid connectivity, Direct To Node multicast/ broadcast	1/eMBB: Regional area public safety, Wide area public safety, Direct to mobile broadcast, Wide area IoT service	1/eMBB: Regional area public safety, Wide area public safety, Wide area IoT service	1/ eMBB: multi-homing, fixed cell connectivity, mobile cell connectivity, network resilience, Trunking, Mobile cell hybrid connectivity	1/ eMBB: Hot spot on demand

Figure 10 – Reference NTN deployment scenarios considered in [19]

Also, adapted channel models were proposed for the context of NTN, with the objective to capture the main specifics of non-terrestrial propagation, taking into account e.g. atmospheric absorption and attenuation, the effects of scintillation (mainly of tropospheric nature for GEOs, and ionospheric-based for LEOs and MEOs), Doppler effect and building entry losses. The study in particular extended fast fading models from existing 3GPP terrestrial and ITU-R satellite models, and provided additional model parameters for various situations in urban, suburban and rural coverage, in LOS or NLOS conditions, and for several frequency bands (here S-band and Ka-band).



The NTN work in 3GPP is focused on “re-using” 5G NR with minimal impact on current specifications. Regarding the class of terminals chosen for the study, **it will be crucial to assess the ability of category-3 UEs, in the context of GEO and NGSO deployments, to realistically support the envisioned use cases. In particular, link budget analysis as well as a reflection on the possible integration of both terrestrial and NTN allocated frequency bands in terminals should help perform this assessment.** Another significant aspect of these 3GPP reports is the early analysis about the impact of specific NTN features on 5G and in particular on NR:

- The various motions of satellites and HAPs (even in the case of quasi-stationary mobility) are analyzed, for instance in terms of impacts regarding handover procedures and issues when trying to adjust offsets such as the timing advances of UEs, using large-latency satellite radio links.
- Likewise, Doppler effects must be carefully studied, although they may be neglected in specific cases or via mitigating techniques such as the use of satellite ephemeris, to limit impacts based on the knowledge of future satellite positions.
- Furthermore, altitude and therefore longer delays should obviously impact NR, e.g. since RTTs observed in satellite generally exceed the traditional HARQ timers and may have a detrimental effect on diverse loop-based procedures like ACM and Power Control schemes.
- Also, both NTN cell size and geometry can impact random access mechanisms: satellite beams are not necessarily projected orthogonally on the ground, so the differences w.r.t. delays at different positions on the beam ground coverage can be significant and may exceed the maximum relative delays as set in terrestrial networks for random access.
- Lastly the choice of duplex schemes (FDD being customarily adopted in the context of satellite communications) as well as the inherent performance of the payload (e.g. regarding phase variations in time domains, non-linearity of power amplifiers, etc.) is also a source of impacts to consider for NR.
- For deep rural (and also off-shore long range) scenarios the service continuity between terrestrial networks and NTN needs to be provided. This is important especially for category-3 UEs.
- Direct-to-mobile access for category-3 UEs might still require a, new, dedicated NTN-category UEs due frequency bands, optimized NTN access mechanisms and ultimately, also specific antenna systems/solution.
- Power consumption reduction for direct-to-mobile access with category-3 UEs needs to be addressed.
- Spectrum regulatory framework needs to be properly defined before final 3GPP specifications. The potential NTN network operator has to deal with the geographical restrictions of their services regulated by local authorities. There are countries/regions where satellite communication are forbidden. If the deep rural area is within one of these countries/regions then, either the NTN access should be allowed or only terrestrial solution would be possible.

Encouraging the integration of Non-Terrestrial Networks (NTN) with greatly expanded reach can help MNOs to provide some level of service to most or all of their territory but requires still a lot of technical and regulation issues to be tackled. Therefore NTN applications are seen twofold:

- Non-Terrestrial Networks (NTN), where GEO, MEO or LEO Satellites provide direct LTE or NR(5G) coverage to the users without having to deploy traditional ground based RAN equipment.
- Utilising inexpensive Satellite backhails by using LEO Satellites which are either have already been launched or will be launched in the near future



6 CONCLUSION

Many countries around the world have sizeable rural populations. While significant in size, rural populations are the most challenging for MNOs to serve, and as a result they are less well connected than their urban peers. Where high speed rural Internet access is accessible, it connects rural residents to electronic services that can bring enormous social and economic benefits. By focusing effort directly on rural connectivity requirements, NGMN can play a role in better connecting these important populations.

Specifically, NGMN can advance requirements in three important areas: coverage enhancement for smartphones, relaying technologies for rural backhaul, and integration of non-terrestrial networks. By making IoT-type coverage enhancement standard features of smartphones, MNOs can see increased cell radius for voice and messaging applications, in addition to improved reliability on these services in a range of environments. Supporting relaying or integrated access-backhaul work that is aimed at rural use – and, in general, network equipment specifically targeting rural challenges – can help to lower deployment costs for MNOs, supporting greater service reach. Finally, encouraging the integration of non-terrestrial networks with greatly expanded reach can help MNOs to provide some level of service to most or all of their territory.

The next phase of the Extreme Long Range Communications for Deep Rural Coverage project aims to explore these areas further and provide guidance or operator requirements to guide standards and implementation.

7 LIST OF ACRONYMS

ARPU	Average Revenue Per User
MCL	Maximum Coupling Gain
AI	Artificial Intelligence
PoP	Point of Presence
GEO	Geostationary satellite
VSAT	Very Small Aperture Terminal
ROI	Return On Investment
NTN	Non Terrestrial Networks
LEO	Low Earth Orbiting
MEO	Medium Earth Orbiting
NGSO	Non-Geostationary Orbiting Satellites
EIRP	Effective Isotropic Radiated Power
MNO	Mobile Network Operator
QoS	Quality of Service
MOU	Minute of Usage

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9 ANNEX A : GROUND TO AIR MOBILE SATELLITE CONNECTIVITY - UMTS AND LTE NETWORK SCENARIOS

1 ABSTRACT

A number of UMTS and LTE Network Architecture scenarios are presented for remote sites which utilise Satellite backhaul for connectivity between various network elements.

2 INTRODUCTION

In this document, a number of practical scenarios of Ground to Air Mobile Satellite Solutions are presented. The presented solutions cover UMTS and LTE Network Technologies and provide a number of deployment variations.

In the scenarios presented, the backhaul between various RAN and Core elements are routed through a GEO Satellite Link.

The scenarios presented in this document illustrate alternative deployment options for remote and isolated areas where investment in backhaul is unviable and/or impractical. Therefore, to achieve network coverage, a number of 'degree of freedom' need to be considered.

The emphasis in all scenarios presented in this contribution is to:

- Extend the coverage as much as practically possible
- Minimise ground infrastructure,
- Minimise the traffic flowing over the satellite links

3 BACKHAUL CONSIDERATIONS

For deployments where:

- The site is in a remote location,
- Microwave backhaul direct line of sight does not exist or requires many hops
- Fibre link from the site to an exchange location is very costly

The only choice remaining is to route the backhaul over a satellite link. This satellite link could be over a GEO/MEO or LEO types of satellite.

As the backhaul over satellite links are very expensive and prone to round-trip delays etc. the network architecture design should aim to reduce the traffic over this expensive link. Therefore, one of the design criteria for this type of architecture should be to minimise the signalling and user traffic on these satellite backhaul links.

4 UMTS SOLUTIONS

The conventions UMTS is based on the evolution of GSM architecture and consists of the following key network elements:

- NodeB- Base Station
- Radio Network Controller (RNC)
- Master Switching Centre (MSC)
- Media Gateway (MGW)
- Serving GPRS Support Node (SGSN)
- Gateway GPRS Support Node (GGSN)
- Home Location Register (HLR)

4.1 Deployment Scenarios

4.1.1 Typical Implementation

The following Figure 11 illustrates a typical GSM/UMTS RAN and Core Architecture where all elements are either implemented in the field or in an equipment room. The transmission between the Core elements in an equipment room are all cable or fibre. Where necessary microwave backhaul is used between the Core and radio elements.

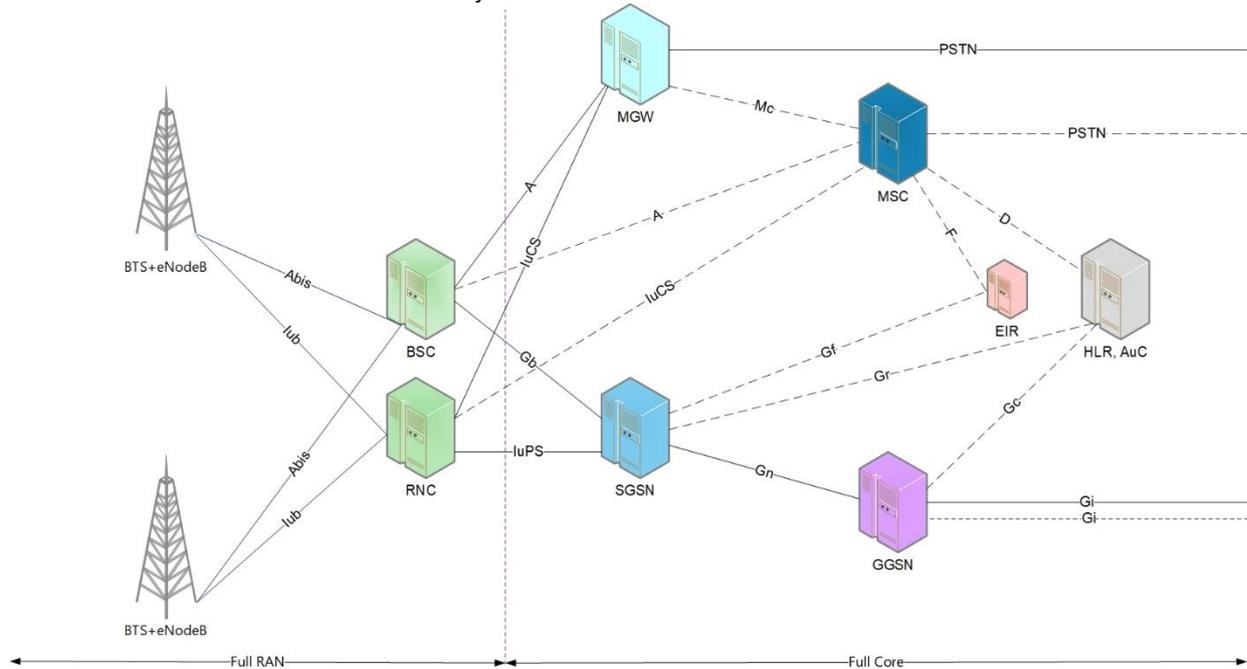


Figure 11 Typical GSM and UMTS RAN and Core Network

4.1.2 Variant 1 Remote Signalling Elements

In the configuration illustrated in the following Figure 12, in order to minimise the traffic over the Satellite link, the signalling elements, such as the MSC, is located away from the Site and the signalling connection is backhauled over the GEO Satellite link. Furthermore, the MGW, which carries all the voice traffic is left close to the Site. Typically, the voice traffic is significantly greater than the signalling traffic.

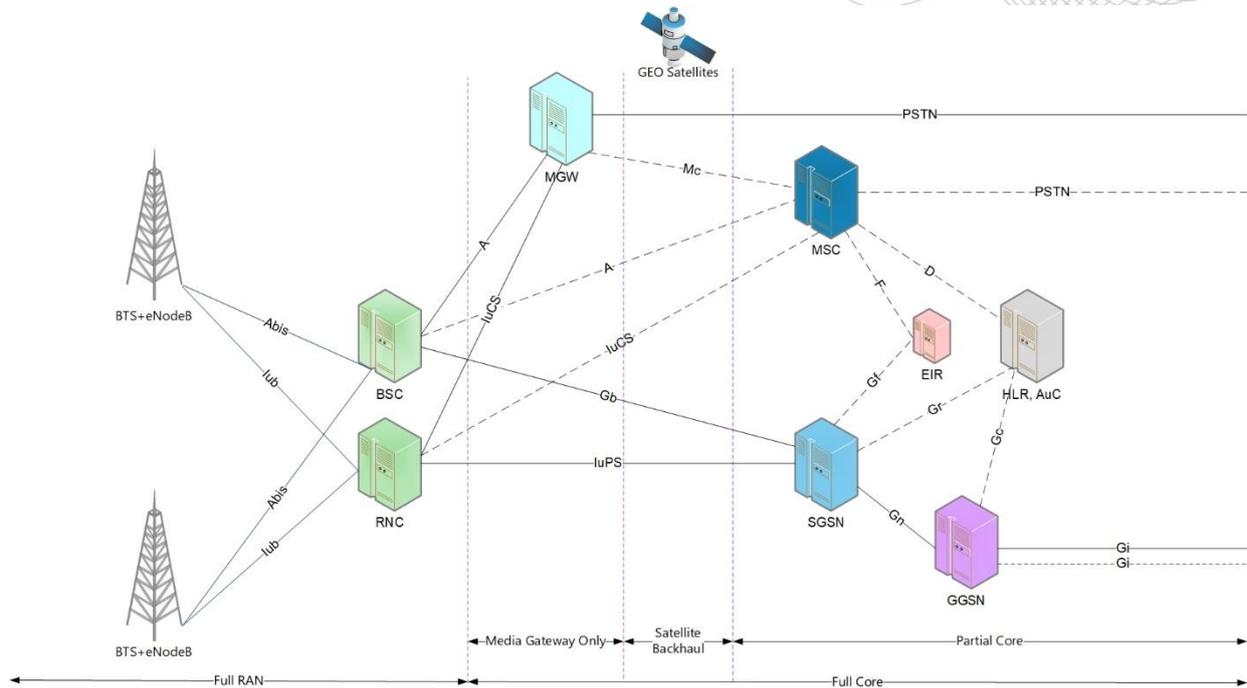


Figure 12 UMTS Network with the Signalling Elements remote to the Site

However, with the SGSN and GGSN implemented remote to the Site, the Data/User Traffic will have to be routed over the Satellite link,

4.1.3 Variant 2 Data Core elements local to the Site

In the following configuration illustrated in Figure 13, the data-intensive elements such as SGSN and GGSN are moved close to the Site, thereby relieving some of the traffic from the Satellite link. In this configuration, some internet data is cached locally during the quiet periods. However, for live internet data such as news and e-mail, the GGSN has to access the internet over the satellite link over the Gi interface.

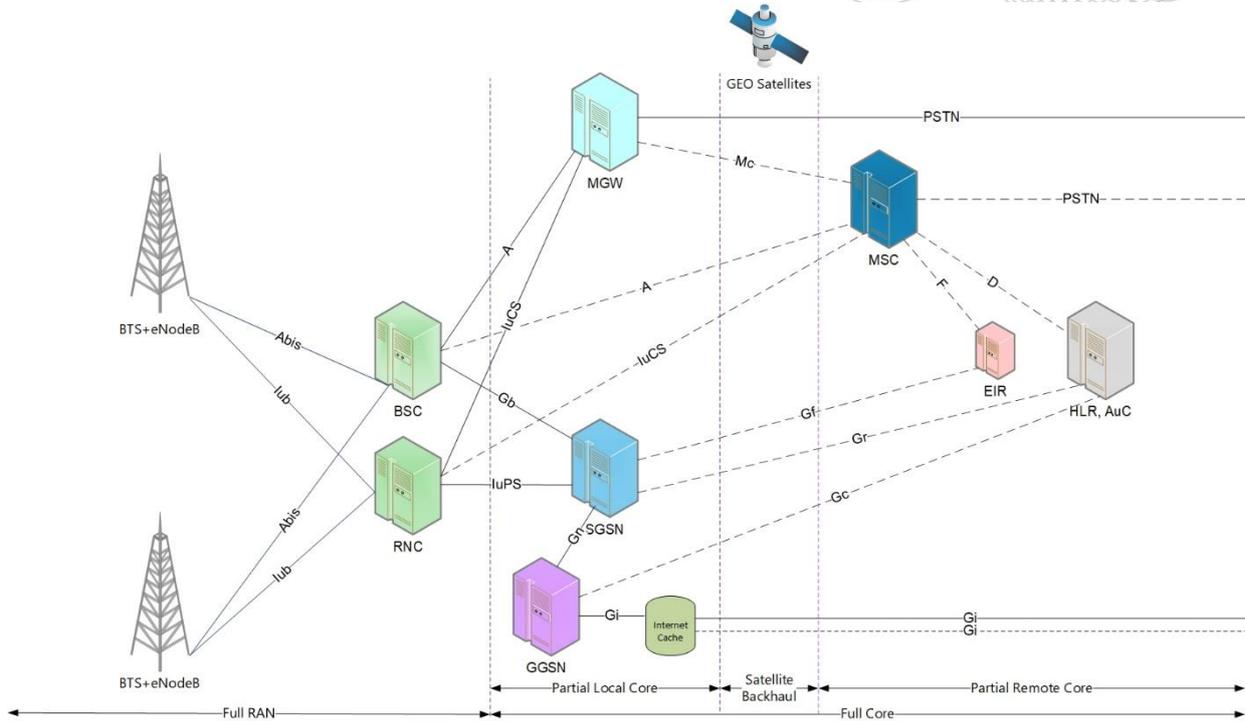


Figure 13 UMTS Network with MGW and Packet Core Elements local to the Site

4.1.4 Variant 3 Virtualised Core Elements

The following Figure 14 illustrates the latest innovation in Virtualisation Technology where the functions of the Core Network elements are virtualised in a “Virtual Machine” type environments.

The virtualised core is implemented close to the Site and backend traffic such as the PSTN and Gi are routed over the Satellite link.

For sparsely populated areas with low traffic volume and where implementation cost is important, the virtualised core solution can provide a very cost-effective solution.

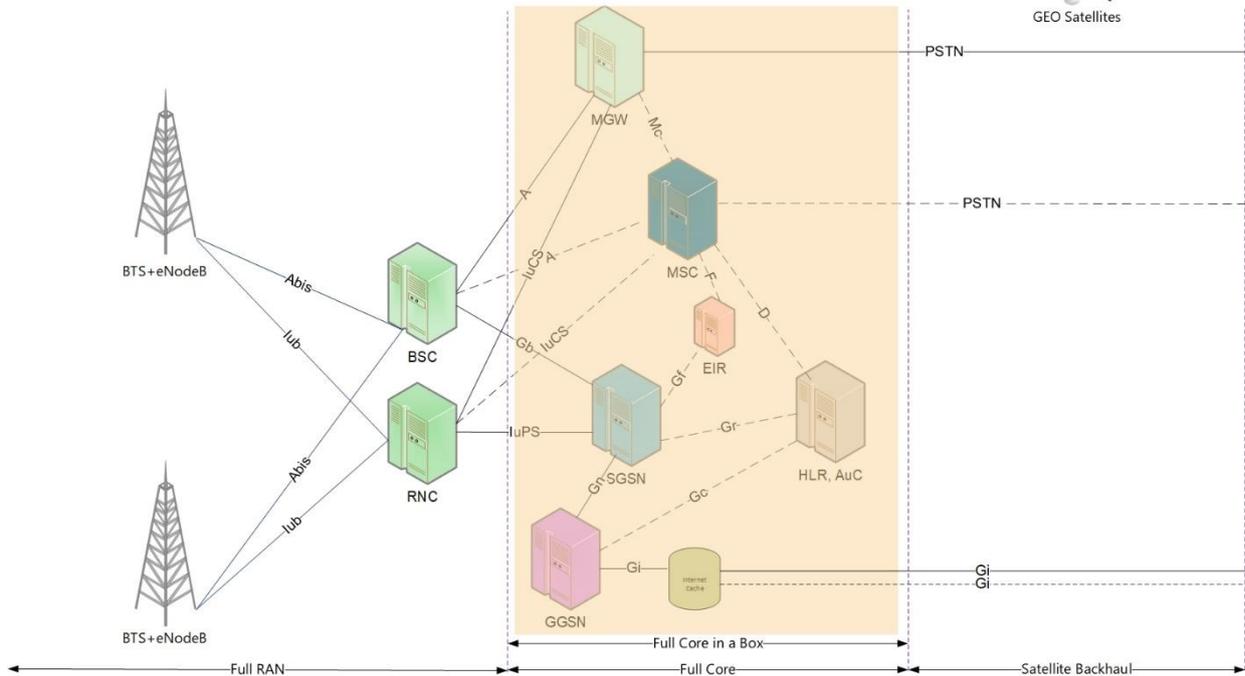


Figure 14 UMTS Network with Core Elements Virtualised in a box

5 LTE SOLUTIONS

The LTE has a flatter architecture than previous UMTS RAN/Core Architecture: in the LTE architecture the functions of the RNC are split between the eNodeB and the Core and to enable a faster data throughput, the signalling and User planes are separated from each other. The signalling and mobility is managed by the MME platform and the User Data is managed and routed by the S/P GW.

5.1 Deployment Scenarios

The following Figure 15 illustrates a typical LTE implementation where the MME and S/P GW are housed in a data centre remote to the eNodeBs. The eNodeBs are connected to the Core elements either by fibre or by microwave backhaul links.

S1-U interface between the eNodeB and carry the most traffic typically over 100 Mbps to each LTE cell.

5.1.1 Typical Implementation

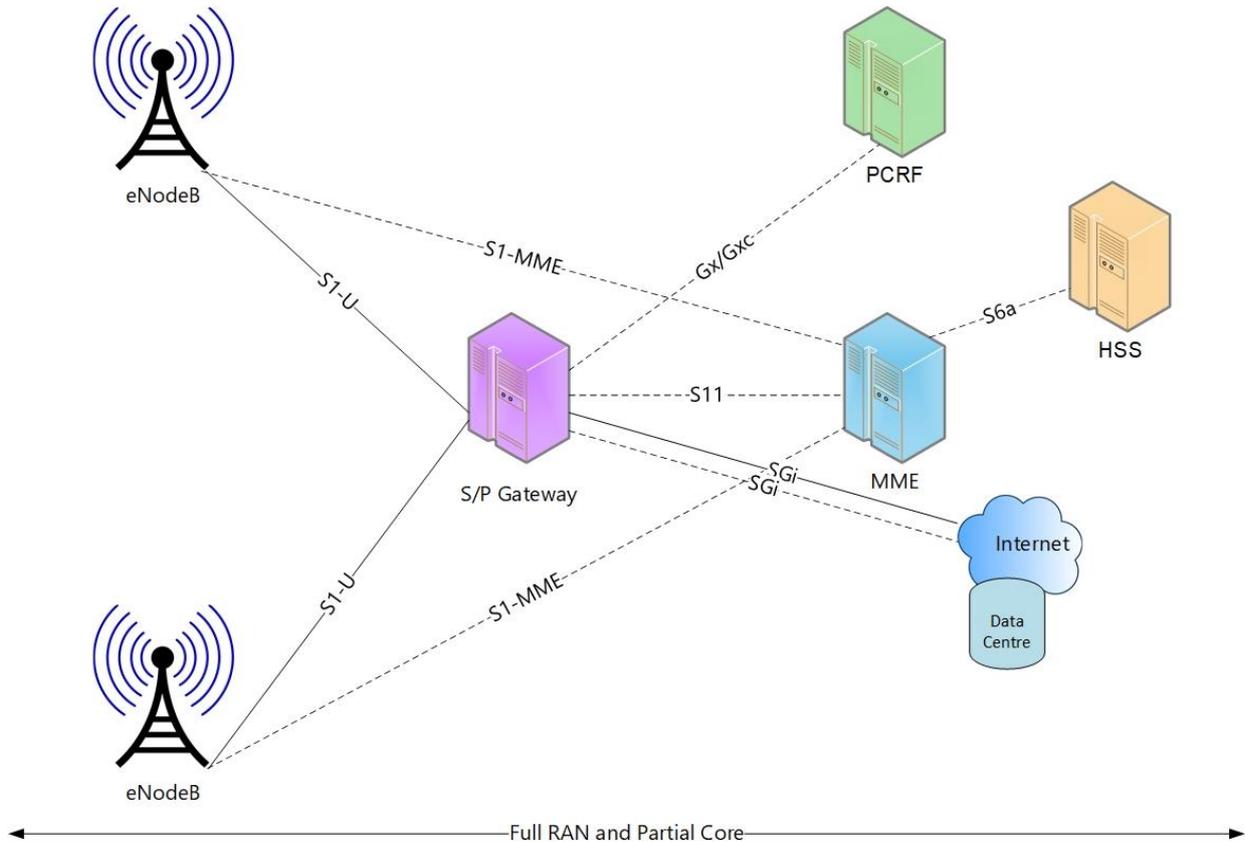


Figure 15 Typical LTE RAN and Core Network

5.1.2 Variant 1 Remote Signalling Element

The following Figure 16 illustrates an example of the signalling elements, which carry lower traffic than the user plane, implemented remote to the site and their interfaces routed over the Satellite links.

In this example the S/P GW is implemented local to the Site with some internet traffic cached locally, however for live internet traffic e.g, news and e-mail, S/P GW need to access the internet over the Gi interface which is routed over the Satellite link.

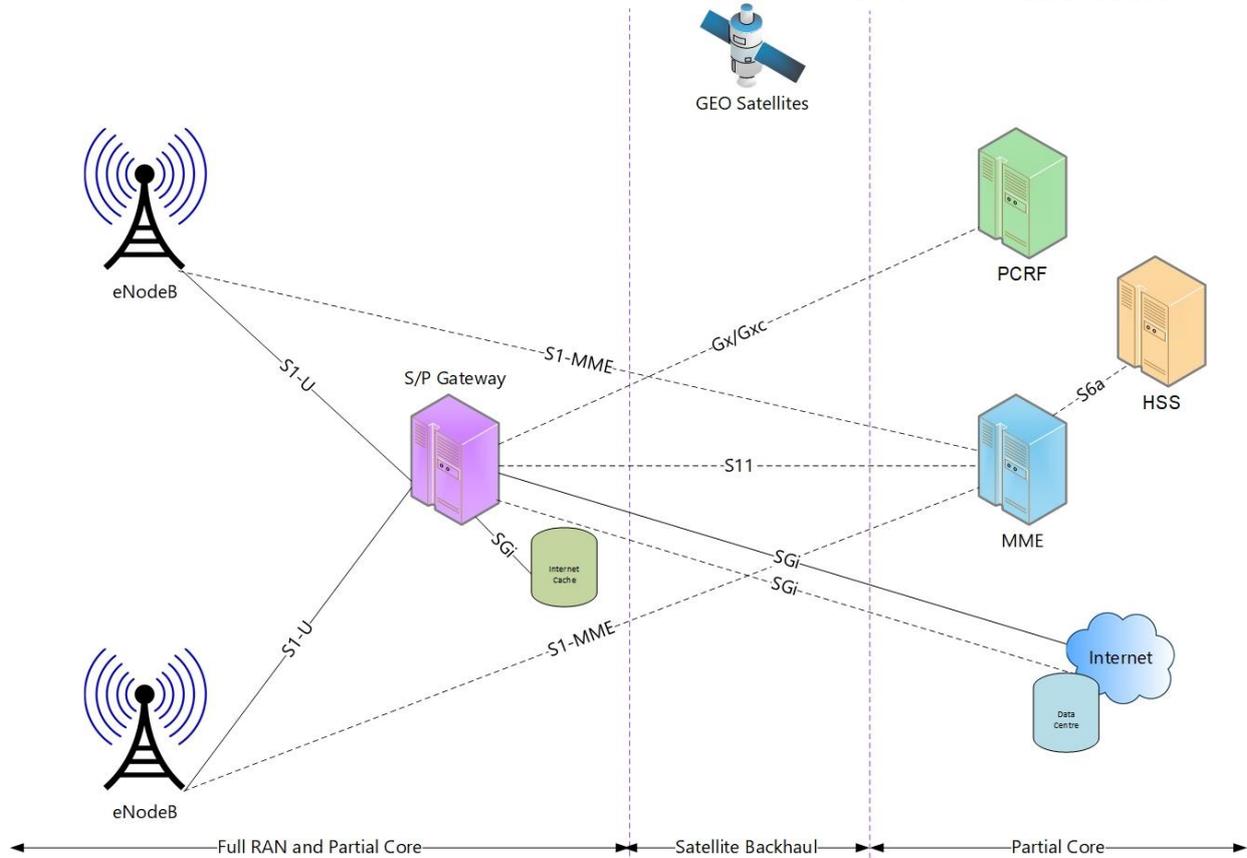


Figure 16 LTE Network with Signalling elements remote to the Site

5.1.3 Variant 2 RAN and Core in a Box

The following Figure 17 illustrates the latest innovation in Virtualisation Technology where various LTE Signalling and User Plane functions are virtualised within a software environment. As illustrated in Figure 17 the virtualise S/P GW, like the conventional platform would still require connectivity with the outside world over the Gi interface and this is routed over the Satellite Links.

For sparsely populated areas with low traffic volume and where implementation cost is important, the virtualised core solution can provide a very cost-effective solution.

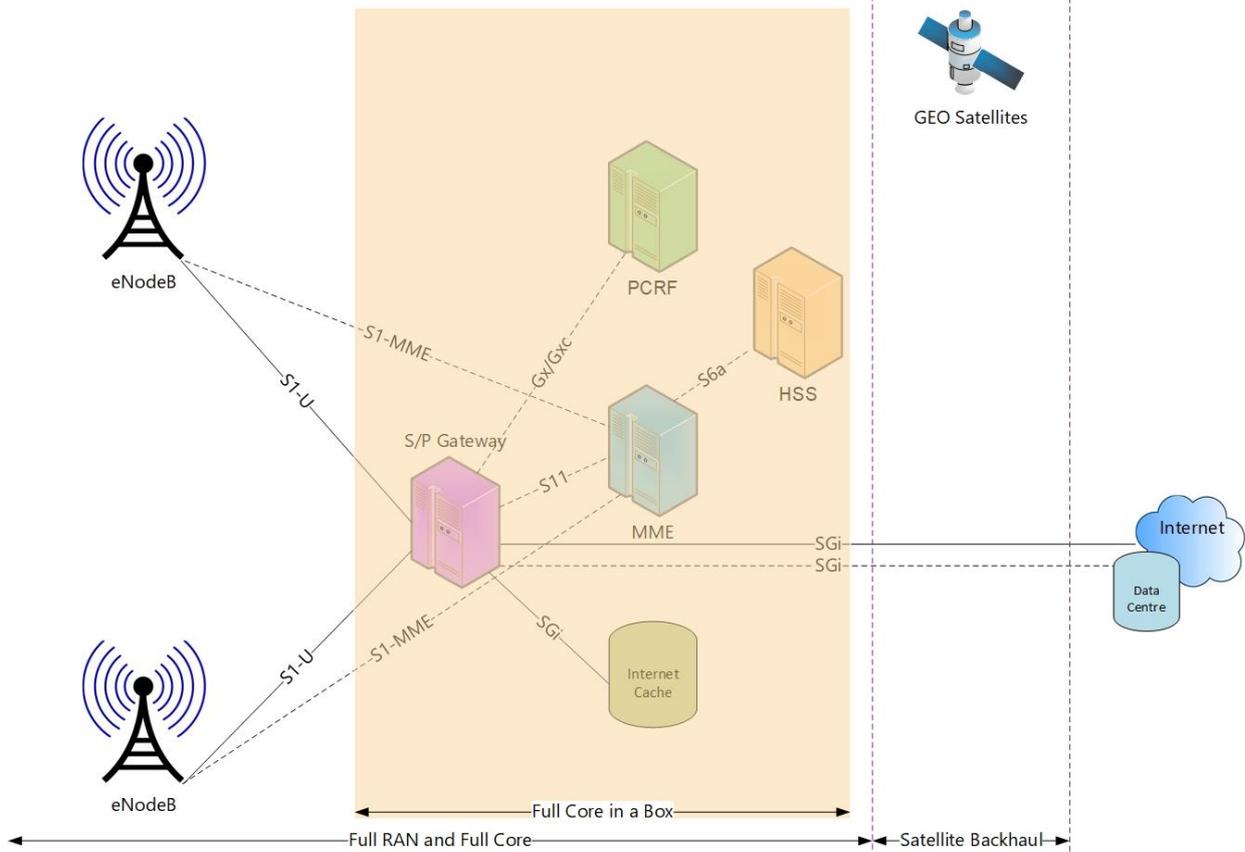


Figure 17 LTE Network with Core Elements Virtualised in a Box

6 VIRTUALISED CORE SOLUTIONS

It should be noted here that for these types of Virtualise solutions, for various signalling and user traffic features, capacity and throughputs features/instances are sold by software licenses in blocks or per user. In general, these types of virtualised implementations are cost-effective for small or low volume applications and as the number of subscribers increase more licenses have to be purchased for these software platforms. In some types of implementations, beyond certain number of users and throughput traffic volume, virtualised core become uneconomical compared to hardware platforms.

It is operator's responsibility to have a practical user and data throughput projection in order to manage the number of features required for the virtualised core.

7 DATA COMPRESSION

For both UMTS and LTE network configurations, connection to the outside/remote internet and other data centres is essential. As it has been illustrated, some of the essential internet traffic can be cached locally, however connectivity with the outside world, over the satellite link is unavoidable.

As satellite traffic is expensive and subject to end to end delay latencies etc. an efficient data compression / decompression technique is proposed to minimise the date sent over the satellite links.

8 CONCLUSIONS

In this contribution a number of UMTS and LTE network scenarios are presented which provide a practical and an efficient implementation to a remote site over satellite links.

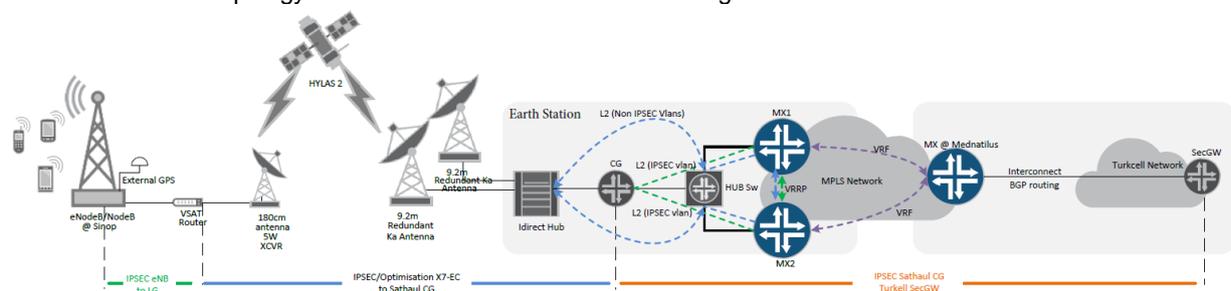
In the first instance, signalling elements, which inherently have low traffic volume, can be implemented remote to the Site and over the satellite links and in some cases non-live internet traffic can be cached locally.

However, in all scenarios presented, and with growing demand for high speed data, it is inevitable that some live internet data has to be routed over the satellite links; this makes supplying data to these remote sites very expensive particularly if expensive GEO Satellite links are used.

In order to arrive at a compromise and balance architectural solution, the user traffic model must first be analysed and base on the internet data usage a suitable Variant implemented.

10 ANNEX B: TURKCELL VSAT - CASE STUDY

At Turkcell Turkey Universal Project a Ka band GEO Satellite solution was tested for 4G with the help of Avanti and Eser Telekom. The topology of the solution is shown in the below figure.



In this satellite transport solution all security protocols (including IP security) are same with Turkcell Universal Project's terrestrial sites. There are three different IPsec processes, first IPsec is between eNodeB and satellite antenna, second IPsec is between satellite antenna and earth station. The third IPsec is between earth station and Turkcell core and data network. There is an data acceleration process between second and third IPsec. By the help of the data acceleration process the 4G data throughputs can be achieved.

The test results, are shown below, mostly acceptable for rural 4G coverage except latency values due to the satellite transmission.

Satellite Band: Ka band

Satellite Backbone Capacity: 60 Mbps

FTP (Multi Session)

- DL: 45.7 Mbps
- UL: 7.7 Mbps
- Ping: 650-1000 ms

VoIP (Turkcell Bip Application)

- Mean Opinion Score (MOS): Average: 4.02, Max:4.25, Min:2.08
- Mouth to Ear (M2E) Delay: Average: 964 ms, Max:1004 ms, Min: 907 ms

Video (Turkcell TV+ Application)

- Video Mean Opinion Score (vMOS): 4.7