



A Case for Large Cells for Affordable Rural Cellular Coverage

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Abstract | In most developing countries across the world, cellular rural users are predominantly pedestrian and indoor users within village homes, and much less from vehicles, let alone fast-moving ones. Specifically, in India, 85% of the villages in the plains are spaced 2–3 km apart uniformly in every direction. The base station required for providing coverage in rural areas is starkly different from the base station along highways to provide coverage for fast-moving vehicles. Till IMT-2020, ITU did not have a rural use case suited to rural needs of developing countries. Hence, the IMT advanced technology development (such as 4G LTE) did not meet the rural requirements in countries like India. To avoid such a situation for 5G, a new test case requirement, named low-mobility large cell (LMLC) was included as a mandatory use case with performance requirements that must be met by every specification that is approved as an IMT-2020 compliant standard. In this paper, we describe the reasons why such a test case requirement is crucial by taking a case study from the Indian rural setting. In addition, we also describe various technical solutions that can be considered to satisfy such stringent requirements. In particular, we look at a new waveform with low peak-to-average power ratio that has been introduced in 5G for coverage enhancement.

1 Introduction

Digital connectivity is an important driver for modern-day economies, and in the current times it is a quintessential necessity for day-to-day living. In India, most services are becoming digital owing to ease of use, customer empowerment and a massive digital initiative push by the government. In cities, broadband access is taken for granted and users connect to the Internet through wired modems in their homes and through cellular broadband connectivity on their mobiles. This mobile connectivity has become especially popular with the advent of 4G wireless networks (LTE), a wireless standard that vastly improved the connectivity speeds and reduced the price per bit. The focus of the 4G wireless standard has been on increasing the data rate, i.e., squeezing more data per hertz of bandwidth. Theoretically, the 4G wireless standard can guarantee a peak

data rate of over 1 Gbps. In urban areas, we see a large number of BS towers that provide the necessary infrastructure to support the large number of cellular users. In contrast, mobile broadband connectivity in rural areas is not very encouraging. This is mainly because of the huge capex costs needed to establish and maintain cellular mobile towers in rural areas, where the return on investment might be lower than in cities. However, most of the Indian population is rural, and the availability of broadband connectivity is critical for bridging the digital divide and the effective implementation of e-governance schemes of government.

Increasing capacity has been the main focus of the cellular industry and the upcoming 5G standard is a reflection of this paradigm. Massive MIMO and MMwave technologies have been introduced in the new cellular standard

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for increasing the capacity of the downlink. The increased downlink capacity translates to better user experience through better throughput, which in turn leads to higher ARPU (average revenue per user). Cell size reduction is an important technique used by operators to achieve higher capacity. Smaller cell sizes lead to a higher bandwidth per user in the downlink, thereby increasing the per-user throughput. In addition, a smaller cell would increase the received signal-to-noise ratio, thereby enabling higher modulation orders for the cell edge users, further enhancing the data rates.

Small cells (user deployed) have been introduced with an aim of providing higher throughput for indoor areas and high density areas. However, user deployable small cells are still not very popular in developing countries like India (even in urban areas) and their large-scale deployment is hindered by the absence of robust backhaul, good interference management and regulatory policy. The coverage and capacity blanket is still provided by macro cells. In countries like India, with huge user density in urban areas, the cell radius of these macro cells is around 200–300 m to maintain acceptable user experience. Since most of the cellular users who can pay a good price for the cellular data are in the urban areas, it is no surprise that most research and standards development focus on macro cells with small serving cell radius. In the last decade, there has been a significantly large body of researchers (both academic and industry) who have studied and understood the various nuances of shrinking the cell size¹. Various interference management algorithms and MIMO techniques have been developed for interference-limited small-sized macro cells. However, there has been very little work on the design aspects of cellular systems for very large cells.

In this paper, we look at the rural environment in India and discuss the newly introduced low mobility large cell (LMLC) ITU model for the rural test environment. We also look at the current 5G NR standard and discuss its limitations for serving large cells required for rural coverage. Several abbreviations are used in this paper and Table 1 provides a list of acronyms and their corresponding expansions.

2 Rural Models in ITU and 3GPP

5G is the next-generation wireless standard with emphasis on higher data rates, machine-to-machine communications and the internet of

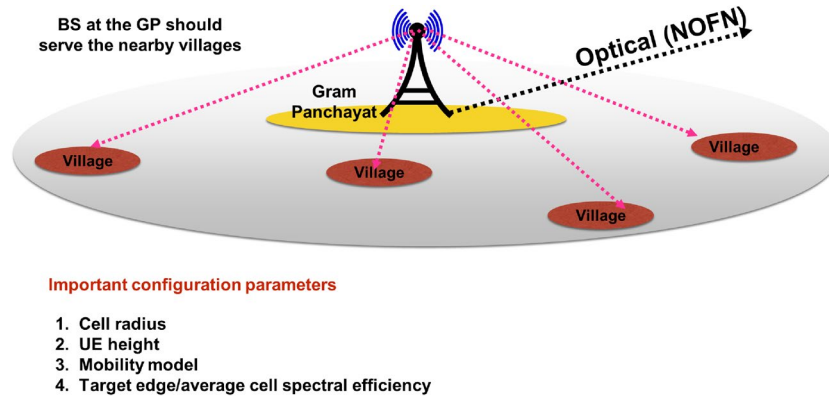
Table 1: Acronyms used in the paper.

IMT	International mobile telecommunications
ITU	International Telecommunication Union
KPI	Key performance indicator
PSS	Primary synchronization sequence
SSS	Secondary synchronization sequence
PDCCCH	Physical downlink control channel
PDSCH	Physical downlink shared channel
PUSCH	Physical uplink shared channel
PUCCH	Physical uplink control channel
PRACH	Physical random access channel
CP	Cyclic prefix
MCS	Modulation and coding scheme
DMRS	Demodulation reference signals

things (IoT). International Telecommunication Union (ITU) is an international body that defines the capabilities and requirements of a wireless standard and ratifies the same for wireless standards developed by other standardization bodies like the 3GPP. These requirements are compiled after a lengthy consultation process with various stakeholders including administrations of various countries. ITU has proposed its vision for 5G and started detailed specifications of the technical requirements of the next-generation wireless standard IMT-2020^{2, 3}. ITU defines several test environments based on the usage scenarios and their corresponding metrics that every technology should surpass to be branded as “IMT-2020 capable”. Currently, ITU defines indoor hotspot, dense urban, rural, MMTc and URLLC as the five test environments. Indoor hotspot and dense urban test environments focus on urban scenarios and target very high data rates. MMTc targets IOT applications, while URLLC focuses on low latency reliable applications⁴. Once the requirements are formulated for the various test environments, various candidate technologies are invited and evaluated for compliance to the KPI. For the purpose of consistent evaluation of the KPI, and the development of technologies, ITU publishes the detailed configurations of the various test environments (use cases) and their associated channel models. These channel models and test cases are also used by 3GPP for the purpose of evaluation and technology development.

Table 2: Traditional rural models used in ITU and 3GPP.

Parameter	Config A	Config B
Carrier frequency	700 MHz	4 GHz
Inter-site distance	1732 m	1732 m
Device deployment	50% indoor, 50% outdoor (in car), randomly and uniformly distributed over the area	50% indoor, 50% outdoor (in car), randomly and uniformly distributed over the area
UE speeds of interest	Indoor users: 3 km/h; outdoor users (in-car): 120 km/h; 500 km/h for evaluation of mobility in high-speed case	Indoor users: 3 km/h; outdoor users (in-car): 120 km/h; 500 km/h for evaluation of mobility in high-speed case

**Figure 1:** A typical cellular deployment in a rural Indian setting.

2.1 Existing Rural Models

Some of the salient features of the original ITU rural test environment are provided in Table 2. We observe that both these models utilize a cell radius of about 1 km and cater to very high-speed vehicles. These two configurations mainly model the high-speed vehicular traffic passing through the rural areas. In fact, one of the main KPIs for these two configurations is the mobility KPI, which looks at maintaining the connectivity for the high-speed vehicular traffic. This original rural test environment is a misnomer and focused exclusively on connectivity of high-speed vehicles (120 kmph) moving in a rural environment. This original rural test configuration was a model of highway connectivity in developed countries and does not reflect the coverage and broadband requirements for rural households, particularly in the developing countries.

2.2 Indian Rural Landscape

In India, about 66% of the population (870 million) live in rural areas spread over 650,000 villages across the country. These villages are non-homogeneous in terms of population and spatial density. Of these villages, about 250,000

villages are larger (compared to their neighbors) and are deemed as administrative centers. They are also termed as gram panchayats (GP).

To improve the rural connectivity, Indian government has started a multitude of programs and initiatives, the most important being the Bharath Net⁵. This is an ambitious program to provide optical fiber connectivity to all the 250,000 gram panchayats across India. Various other projects to provide e-governance, e-health, and e-education using this optical backbone are in pipeline. However, last mile connectivity is still an issue as the fiber drop points terminate at the GPs. The idea is to use the optical drop point in a GP to provide broadband connectivity to nearby villages and fields. There are a multitude of ways to provide this last mile connectivity. While wired connections are possible, they are expensive as this would require a lot of new fiber to be laid and maintained (Fig. 1). It is generally agreed that wireless connectivity would provide the most flexible and cost-effective last mile connectivity from the GPs to the neighboring villages.

A simple way to solve this last hop connectivity problem and provide mobile broadband

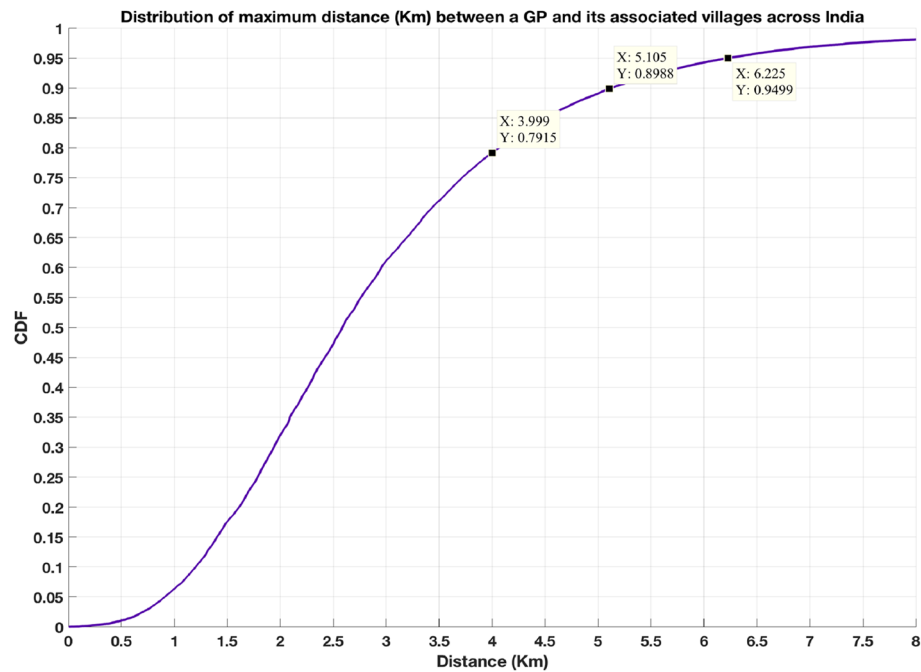


Figure 2: A CDF of the distribution of the villages in a rural Indian setting.

connectivity to the villages is to install a cell tower at each optical drop point in a GP that can serve the neighboring areas. Since the tower will be put up near the optical drop point, the backhaul (interconnection of the BSs to the network center) is automatically taken care of, leading to lesser capital equipment cost (capex) cost for the operator. In addition, if the wireless technology can support large areas and cover the nearby villages, then the capex would further decrease for the operators as the rural areas can be covered by fewer base stations. In Fig. 2, we show a typical distance distribution between the villages and the closest gram panchayats. The following methodology is used in collecting this distance distribution.

- The locations of all the villages and gram panchayats in India are obtained from government databases⁶ and cleaned up using Google maps API.
- Each village is associated to its closest GP.
- The distance from a village to its associated GP are noted for obtaining the distribution across the country.

From Fig. 2, we can observe that a radius of 3 km from the cell tower (at the fiber drop point in GPs) can only cover 60% of the villages, a radius of 6 km from the cell tower can only cover 95% of

the villages, and a radius of 8 km can cover 98% of the villages. Note that a radius of 8 km corresponds to an inter-site distance (ISD, in cellular terminology) of approximately 14 km.

For cellular last mile rural connectivity to be a reality through IMT-2020 (5G), the key is to have future technologies that can support large cells. Any technology that can enable a base station cover 6 km, and provide decent data rates in the covered area, would help to solve the basic last mile rural connectivity problem for about 95% of the villages.

In contrast, the rural models in ITU (and 3GPP) mainly focused on cell sizes of 1 km radius, which is not sufficient even for 10% connectivity⁴. Such small cells would require a base station to be put in every village, massively increasing the deployment cost, thus making it non-viable. Even if deployed, such massive deployment might solve the problem of broadband connectivity, but it will not solve the issue of farm coverage (for farm automation through IoT). Most technology (while being developed for IMT-advanced), for, e.g., 3GPP LTE, has been designed and simulated for the 1.732 km ISD, thus making the large cell connectivity required for rural areas an afterthought. Hence, the villages were severely underserved or the cost of rural deployment was significantly high.

Table 3: LMLC test configuration.

Parameter	Config A	LMLC
Carrier frequency	700 MHz	700 MHz
Inter-site distance	1732 m	6000 m
Device deployment	50% indoor, 50% outdoor (in car) Randomly and uniformly distributed over the area	40% indoor, 40% outdoor (pedestrian), 20% outdoor (in-car), randomly and uniformly distributed over the area
UE speeds of interest	Indoor users: 3 km/h; outdoor users (in-car): 120 km/h; 500 km/h for evaluation of mobility in high-speed case	Indoor users: 3 km/h; outdoor users (pedestrian): 3 km/h; outdoor users (in-car): 30 km/h

Config A is included for comparison

2.3 Low Mobility Large Cell Configuration

LMLC (Low Mobility Large Cell) is a new configuration that India introduced as a new sub-configuration of the Rural eMBB test environment in ITU toward IMT-2020 evaluation methodology⁴. This new configuration focuses on low mobility users (a mix of pedestrian with speeds less than 3 kmph and vehicles at 30 kmph) and inter-base station distance upward of 6 km. Unlike the other rural cases, LMLC does not focus on high-speed mobility. The salient features of the LMLC test configuration is shown in Table 3. In addition to the test configuration, a new channel model was introduced for the LMLC rural scenario to aid in the simulation of large cells. This new channel model is valid for a cell radius of up to 20 km⁴.

This distance of 6 km ISD for LMLC was arrived after a lengthy consensus building exercise between the Indian administration and industry.¹ Also, for the LMLC test configuration, average spectral efficiency was accepted as a mandatory KPI that has to be satisfied by all IMT-2020 technologies. The cell edge spectral efficiency for LMLC was not accepted as a requisite KPI for IMT-2020. While not sufficient, for exhaustive rural coverage, LMLC was a step in the right direction by ITU in increasing the cell size requirement for rural connectivity when compared to the IMT-Advanced technologies.

3 Issues with Current Technologies

In this section, we discuss the issues with the current deployments and widely used cellular technologies such as LTE and 5G NR for large coverage. The potential solutions to address these issues are discussed in the next section.

The various physical channels used for communication between base station and user equipment in these cellular technologies are

downlink synchronization signals (PSS, SSS), downlink control channel (PDCCH), downlink shared channel (PDSCH), uplink synchronization signal (PRACH), uplink control channel (PUCCH) and uplink shared channel (PUSCH). Apart from this, there are other reference signals such as demodulation reference signal (DMRS) and sounding reference signal (SRS). In a cellular deployment, typically coverage is limited by the uplink because of limited UE transmit power and also several other UE hardware restrictions. Hence, in this paper, we will focus only on the uplink physical channels and how their current design limits the coverage.

3.1 PRACH

Initial uplink synchronization in 4G/5G is a four-step process which is also referred to as PRACH procedure. In the first step, in LTE and NR, a Zadoff–Chu (ZC) sequence is sent by the UE at specific time intervals as indicated by the BS. The BS then uses the correlation properties of the ZC sequences to estimate the time offset that must be compensated by each UE, so that all UE's signals are received within the CP boundary at the BS receiver. The ZC sequence design in LTE and NR is such that cell sizes of 100 km can be supported by using long transmissions and also via repetitions. However, this is only applicable for the preamble transmission which is only one step out of the four steps required for completion of the uplink synchronization procedure. Steps 2 and 4 involve downlink transmission from the BS to the UE, which by using the higher BS transmit power can be enabled to support very large cell sizes. However, step 3 is in the uplink direction, wherein the standards prescribe the use of QPSK modulation with ZC as a reference signal. This configuration limits the coverage that can be attained, i.e., this limits the set of the UEs that can attach themselves to a particular BS. The reason for the limited coverage due to this transmission mechanism

¹ The initial proposal was to support 12 km ISD.

is explained next. Further, this step in the PRACH transmission does not have any mechanism for repetitions or adaptive modulation and coding mechanism assignment to ensure long coverage. Hence, the uplink synchronization procedure will be limited by the step 3 transmission and remedial measures are required to enhance the coverage of PRACH for very large cells.

3.2 PUCCH

PUCCH is an uplink control signal used for carrying ACK/NACK or channel state information feedback. Several PUCCH transmission mechanisms are allowed in these technologies to suit a variety of use cases such as user multiplexing and long coverage. Both in LTE and NR, the coverage for the PUCCH channel is enhanced by using time and frequency domain repetitions of the same data symbols. Specifically, it has been observed in several studies that they can support SNR of -14 dB which is typically seen at cell edge areas with ISD around 12 km. However, the reference signals used for these transmissions are ZC sequences which have high PAPR (shown in next section) and will require larger back-off for the power amplifier to avoid non-linearities (discussed shortly). Therefore, the existing mechanisms are still not enough to achieve the required coverage.

3.3 PUSCH

For the data channel PUSCH, adaptive modulation and coding scheme mechanism will ensure low code rates (i.e., heavy coding) assignment to cell edge users to ensure reliable demodulation in harsh environments. However, to support users at cell edges in case of ISD = 12 km or longer, we will need to support SINR in the range of -14 dB. This seems not possible in LTE technology. However, to support extreme long coverages for the case of NB-IoT devices, as many as 64 repetitions are allowed which allows for coverages of the order of 100 km while supporting data rates of only a few bits per second. This idea was carried over to the design of 5G NR and a maximum of eight repetitions across slots is allowed in NR. However, this seems not enough to achieve low SINR ranges of -14 dB to support data rates to ensure broadband connectivity even in rural areas. Therefore, additional physical layer mechanisms are needed to be coupled with this repetition mechanism to make the standard compatible for long coverage regions.

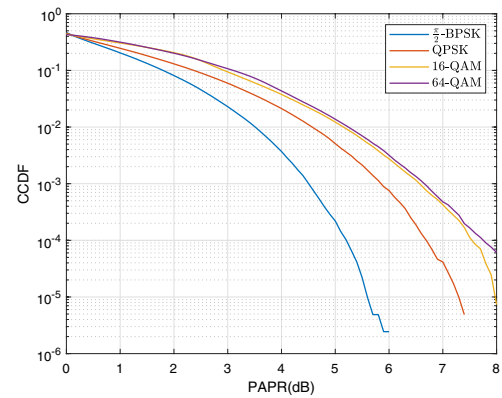


Figure 3: PAPR of different modulation schemes using a DFT-s-OFDM waveform.

3.4 DMRS

In LTE, ZC sequences are used as reference signals for the uplink. While the PUCCH and PUSCH channels use low-PAPR DFT-s-OFDM waveform, there is no DFT spreading done for the ZC sequence. QPSK is the lowest modulation order used in LTE. The PAPR of QPSK waveform with DFT-s-OFDM transmission is high as shown in Fig. 3. This high PAPR limits the coverage of the uplink in the LTE system as the transmit power must be backed off to avoid any non-linear distortions which automatically reduces the coverage of the uplink transmissions.

Similarly in 5G NR, Rel-15 uses ZC-based DMRS sequences resulting in the same problems as that of LTE. A new waveform, namely $\pi/2$ BPSK, was introduced in NR to support low PAPR transmissions. While the data transmissions support low PAPR transmission, the reference signal is still ZC, which will still limit the coverage as in LTE, thereby losing any advantages of the low PAPR $\pi/2$ BPSK data waveform. More details about this $\pi/2$ BPSK waveform are given in the next section.

3.5 SRS

Typically, SRS is used either for uplink frequency selective scheduling or for acquiring uplink channel state information which can be used for MIMO scheduling in TDD networks. However since the focus of this paper is to discuss about coverage in large cell regions, SRS is not a crucial signal. A UE which is at the cell edge may still be connected to the BS without the presence of this signal.

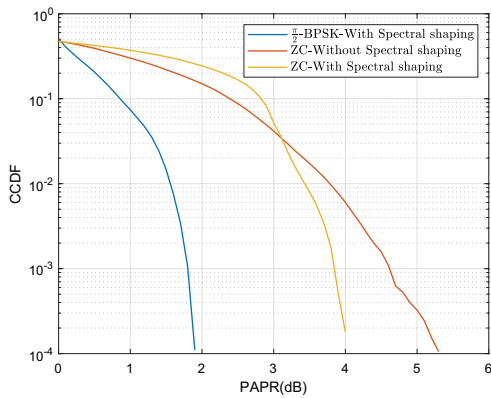


Figure 4: PAPR of $\frac{\pi}{2}$ -BPSK waveform with spectrum shaping and ZC sequence with and without spectrum shaping.

3.6 Power Amplifier Related Issues

In the uplink, sufficient power is needed to ensure higher coverage. As a user moves toward the cell edge, higher transmit power is used to ensure a minimum SNR so as to maintain a reliable link. However, when the PA starts transmission close to its peak rating, it quickly enters into the saturation region. This will cause non-linearities which in turn create unwanted interference and distortions in the transmitted signal. Hence, typically, the transmissions are backed off by a few dB (from the saturation of the PA) to avoid this. This lower average power limits the uplink coverage of the cell. Hence, again novel mechanisms are required for exploiting the full range of a PA.

Having illustrated the potential issues with the current technologies, we will next describe the potential solutions to overcome these challenges in enhancing the coverage of the cellular technologies.

4 Potential Solutions

The design of 3GPP 5G NR (Release 15) heavily focused on enhanced mobile broadband access for urban areas with little focus on rural coverage. 3GPP and most IMT 2020 evaluations are limited to 1.732 km inter-site distance (ISD) which does not capture the required rural scenario with 12 km ISD. A preliminary analysis shows that 5G NR fails to perform well at such extreme coverage settings. This design will therefore not work in rural Indian settings which requires larger coverage. In this section, we focus on the following four solutions that increase the uplink coverage:

- Newer waveform designs for enhanced coverage.
- Low PAPR reference signal design.
- Lower MCS for supporting lower SNR's.
- Better beamforming capabilities.

Other potential solutions should also be explored for extending the current standards for supporting large coverage areas.

4.1 Waveform-Related Enhancements

For a cellular network, uplink transmissions define the coverage area. This is because the transmission power in the uplink is limited to 23 dBm⁷ at the user equipment (UE) owing to hardware limitations (such a battery size, PA sizing, thermal limits and cost considerations) and regulatory constraints as opposed to 43 dBm at the base station in the downlink. This limited transmission power in the uplink must therefore be used carefully to enhance cell coverage without increasing the CAPEX/OPEX costs of deploying more cell sites. Therefore, the uplink design of a cellular standard is crucial in enabling uplink transmissions at high powers.

With a goal of increasing uplink coverage, a new waveform $\frac{\pi}{2}$ -BPSK was introduced for the uplink data channel (physical uplink shared channel—PUSCH) and control channel (physical uplink control channel—PUCCH) transmission was introduced in 5G NR for the DFT-s-OFDM mode. This new waveform has the following salient properties:

1. When the $\frac{\pi}{2}$ -BPSK waveform is passed through an appropriate spectrum shaping filter, the resulting waveform has very low peak-to-average power (PAPR) ratio^{8–10}. The PAPR of $\frac{\pi}{2}$ -BPSK with spectrum shaping is illustrated in Figs. 3 and 4. We observe that the PAPR of $\frac{\pi}{2}$ -BPSK with spectrum shaping is about 2.5 dB lower than QPSK modulation.
2. $\frac{\pi}{2}$ -BPSK with spectrum shaping waveform is resilient to non-linearities. It is shown in^{10, 11} that the power amplifier can be driven to saturation (adjacent channel leakage ratio (ACLR) and error vector magnitude (EVM) will still be within the required specification limits) and the error rate performance of this modulation scheme is not compromised.

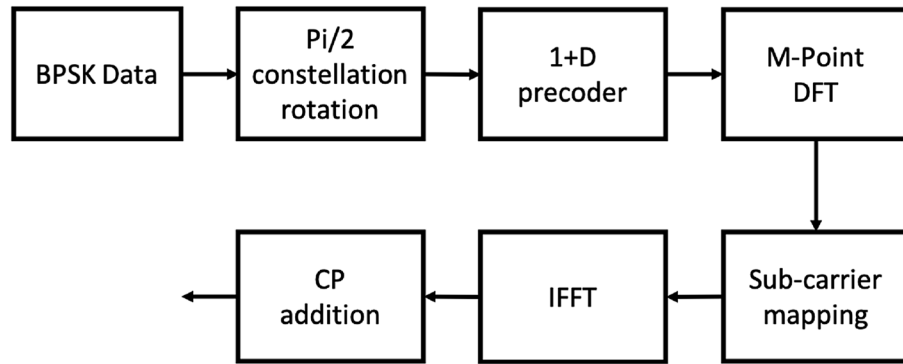


Figure 5: $\frac{\pi}{2}$ -BPSK transmitter chain for a DFT spread OFDM uplink.

The first property reduces the required back-off from the saturation and help in increasing the average uplink power. Because of its resilience to non-linearities, the PA can be driven to saturation without increasing the error rate. Hence, this modulation scheme can enhance the cell coverage for 3GPP 5G NR-based cellular networks.

A transmitter chain for this $\frac{\pi}{2}$ -BPSK modulation scheme is shown in Fig. 5. BPSK data is first passed through a $\frac{\pi}{2}$ rotation and subsequently passed through a two tap spectrum shaping filter given by $[1, 1]/\sqrt{2}$. Thereafter, the resulting data are passed through a DFT-s-OFDM chain.

The maximum transmit power for a target ACLR of -30 dBm (as per 3GPP specifications) for various modulations is provided in Table 4. A PA model with 25 dB saturation is used for modeling the non-linearities. It is clearly seen that $\frac{\pi}{2}$ -BPSK waveform with spectrum shaping can be transmitted close to the peak power of the PA, while the regular QPSK modulation scheme can be transmitted only up to 21 dBm. Hence, QPSK has a lower uplink transmit power and hence coverage. It is for this reason that $\frac{\pi}{2}$ -BPSK waveform was introduced in the 3GPP 5G NR standards. In addition, since $\frac{\pi}{2}$ -BPSK is a low-order modulation scheme, it is also tolerant to any distortions and the power amplifier can even be pushed into its non-linear region without any significant impacts on the demodulation. Therefore, a change in the transmit waveform will also help us overcome the power amplifier-related challenges.

4.2 Reference Signal Design

The demodulation reference signals (DMRS) employed in Rel-15 for coherent demodulation

Table 4: Transmit power for various modulation schemes for a given ACLR value.

	Tx power (dBm)	ACLR
$\frac{\pi}{2}$ -BPSK	23	-30.5
$\frac{\pi}{2}$ -BPSK with spectrum shaping	24.8	-32.7
QPSK	21.7	-30.86
Random OFDM signal	19.1	-30.4
Zadoff-Chu sequence	24.35	-34.54

A PA which saturates at 25 dBm is used. Observe that $\frac{\pi}{2}$ -BPSK can be transmitted at almost 3 dB higher power compared to QPSK while still meeting the ACLR specification

of the PUSCH and PUCCH are generated using Zadoff-Chu (ZC) sequences or QPSK-based computer generated sequences (CGS) as specified in Section 5.2.2 in⁸ and Section 6.2.2 in⁹. The PAPR of these sequences is around 3.5–4 dB when spectrum shaping is employed, which is higher than that of the spectrum-shaped data transmissions^{12–14}. This is also shown in Fig. 4. Therefore, even though the data transmissions have low PAPR and potentially allow for larger coverage, the DMRS design still limits the cell size due to its high PAPR in Rel-15 3GPP 5G NR. Note that the performance of PUSCH and PUCCH channels directly depend on the quality of the channel estimates obtained using these DMRS sequences. Hence, when the DMRS sequences are transmitted at lower power to avoid PA saturation, the coverage of PUSCH and PUCCH channels is automatically limited. For this reason, 3GPP introduced a new study item in Rel-16 to design new reference signal sequences with

lower PAPR. These sequences can be used for both PUCCH and PUSCH (even for step-3 of PRACH transmission, which will address the PRACH coverage issues) channels. For more details on the Rel-16 design, the transceiver design for reference signals and data, please see¹⁵.

4.3 Bit Level Processing

Low rate error correcting codes help in decoding at lower energy per bit (or SNR) and hence increase the coverage. This needs changes in the MCS tables specified in 3GPP and RRC signalling to indicate the relevant information. This may also be supported by allowing repetitions of the same data over multiple time slots such as that done in the case of narrow band IoT, which allows for up to 64 repetitions across 64 subframes to support coverage up to 100 km while simultaneously supporting data rates of the order of a few Mbps. Similarly, either repetitions or lower code rates can be used for step 3 of the PRACH transmission to address the coverage issue of PRACH signal.

4.4 Beamforming

In the sub-6 GHz band, currently 3GPP NR supports a maximum of 8 synchronization signal blocks, which can be used to cover various different directions of a cell. These directions are used for synchronization and data transmission in both downlink and uplink directions. This number may be enhanced to 64 to allow for finer beamforming and deeper coverage to support large cell sizes in rural settings. Again, this must be accompanied by relevant changes in the signalling such as master information block in 5G NR and others.

5 Conclusion

In this paper, we first discussed how various technologies are evaluated by several international organizations by considering various deployment scenarios. We then discussed how these evaluation criteria were not accurately modeling the geography of developing countries like India and discussed in depth the motivations and reasons for deploying large cells by providing a case study of Indian villages. We then discussed various reasons why the current cellular technologies are not suitable for deployments with such extreme coverage requirements. Finally, we discussed potential solutions which can be used to enhance the

coverage of these existing technologies to match the requirements of developing countries such as India.

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Prof. Kiran Kuchi is a member of faculty at the Department of Electrical Engineering, IIT Hyderabad (IITH). He is also the founder and CEO of WiSig Networks, a 5G wireless start-up based out of Hyderabad. Prof. Kuchi has been leading Indian 5G research and standards development efforts through his leadership role in TSDSI (Telecom Standards Development Society, India) and participation in 3GPP (Third Generation Partnership Program), a body that develops 5G standards and specifications. Prof. Kuchi's team introduced a number of key 5G/IoT technologies in 3GPP, including a new waveform that doubles the transmission power of handsets and IoT devices, a key feature that increases the communication range of 5G networks. Prof. Kuchi spearheads the Government of India funded "Indigenous 5G Testbed" program, a 40 Million USD research grant given to several IITs to develop "An End-to-End 5G system". Prof. Kiran Kuchi lived in USA between 1995 and 2008 before he moved back to India to join the IIT system. He holds both M.S. and Ph.D. degrees in electrical engineering from The

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Dr. J. Klutto Milleth obtained the Ph.D. degree in space-time wireless communication in the year 2004 from IIT Madras. He has more than 28 years of teaching and research experience. He is a Chief Technologist at CEWiT, IIT Madras, and he has been with the center since October 2004. He is currently leading a team comprising of over 40 people with a research and development focus mainly on the L1, L2, and L3 layers of 4G and 5G Broadband Wireless Communication systems. He has gained rich standardization experience by participating and significantly contributing in the 4G and 5G technology development by IEEE 802.16m (WiMAX-2), 3GPP-LTE, and 3GPP-NR. Currently, he is working on the 5G wireless technologies and driving the 5G research and development activities within CEWiT. The two major projects which he is leading are the collaborative projects in 5G involving leading IITs and IISc for standards-based research and the L1, L2, and L3 layer implementation of a massive end to end 5G NR testbed. Apart from the above, he is also handling Industry projects from public and private industries including Indian Railways and Defence departments. His research activity till date has led to publications in 15 leading international conferences and seven reputed international journals. Moreover, he has filed 38 patents in India and US, and 12 of them were already granted. He had served as a committee member high-level task force setup by the Government of India related to 5G. He is also a member of the 5G implementation cell for 5G India 2020 constituted by MEITY, Government of India.



Prof. Bhaskar Ramamurthi got his B.Tech. degree in electronics from IIT Madras in 1980, and his M.S. and Ph.D. degrees in electrical engineering from the University of California at Santa Barbara, in 1982 and 1985, respectively. After working at AT&T Bell Laboratories for a couple of years, he joined the faculty of IIT Madras, his alma mater, in 1986. He took over as Director, IIT Madras, in September 2011. His areas of specialization are communications and signal Processing. His research work is in wireless networks, modulation, wireless data, and audio and video compression. He is currently also an honorary Director of the Centre of Excellence in Wireless Technology, a public-private initiative at the IIT-M Research Park to make India a wireless technology leader. He is on the Board of Bharat Electronics Limited. He is currently the Chairman of the Telecommunications Standards Development Society, India (TSDSI). He is a Fellow of the Indian National Academy of Engineering, and the Institute of Electrical and Electronics Engineers (IEEE). He was awarded the Vasvik Award for Electronic Sciences and Technology for the year 2000, the Tamil Nadu Scientist Award for Engineering and Technology for the year 2003, India Semiconductor Association TechnoVisionary Award for the year 2011, Doyens of Madras Award for the year 2014, and ACCS-CDAC Foundation Award for the year 2015.