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AN ONLINE LEARNING TOOL FOR 5G RADIO ACCESS NETWORK DIMENSIONING

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Abstract

The digital-skill gap in the telecommunication industry is widening with the rollout of fifth-generation (5G) cellular networks. The subject of cellular network planning is traditionally taught in advanced university or training courses, mostly in a passive manner because of the lack of suitable hands-on learning tools for effective teacher-learner interactions. Grasping the underlying principles of this subject is often difficult due to the complex interrelationships and high dimensions of the many factors and parameters involved in the network planning process. To fill this gap, this study introduces a standards-compliant 5G radio access network dimensioning (5G-RAND) tool to facilitate active learning of 5G network pre-planning. The 5G-RAND tool has been developed using interactive worksheets with interworking coverage and capacity site count calculators engineered to ensure efficient duplex communications. It allows network planners to track, analyse, and observe the dimensioning outcome by tinkering with network goals, equipment specifications, and channel conditions. Moreover, the tool has been made available online, enabling experiential e-learning of 5G network pre-planning while paving the way for learning more advanced detailed network planning. Classroom observation data collected revealed that learners exposed to the tool demonstrated increased attention and interest in the subject while significantly improving their test scores.

Keywords: 5G, e-learning, Interactive tool, Radio network dimensioning, Radio network planning.

1. Introduction

The fifth-generation (5G) wireless cellular network is engineered to achieve unprecedented performance in terms of capacity, throughput, and latency. In addition to serving consumers for enhanced mobile broadband communications, 5G is also required to fulfil the requirements of ultra-reliable low-latency communications and massive machine-type communications for diverse industry verticals. With these capabilities in place, 5G networks are envisioned to support massive internet-of-things and mission-critical applications such as industrial control, autonomous driving, and remote medical procedures.

Similar to its predecessors, the service area of a 5G network is divided into pre-dimensioned geographical areas known as cells. As shown in Fig. 1, the 5G wireless devices in a cell are first connected to the radio access network (RAN) via radio signals, then to the core network through a fibre or wireless backhaul link. The 5G RAN, which follows the 5G New Radio (NR) standards [1-3], includes multiple base stations (BSs) or cell sites that cover the desired service area. A cell is typically served by at least one BS. To ensure a smooth rollout of 5G networks, operators need to plan ahead and identify the deployment approach which makes the best investment and supports their business strategies.

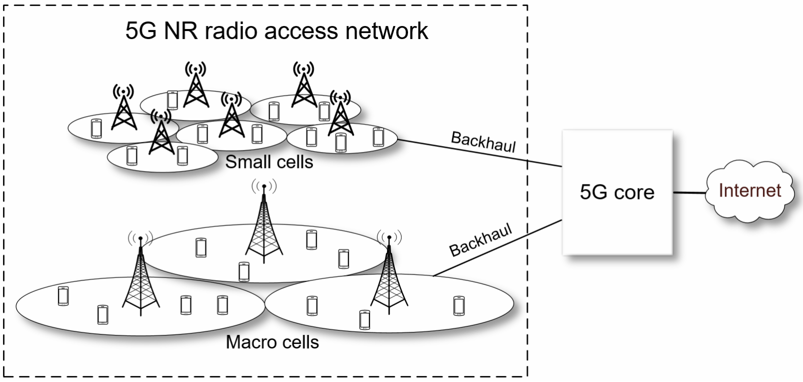


Fig. 1. 5G cellular network architecture.

5G NR networks will become increasingly heterogeneous constituting different cell sizes operating at different frequency bands, thereby posing significant challenges with respect to network planning (NP) and optimisation. NP is carried out to determine the number, location, and configuration of BSs or cell sites in order to achieve a network topology that meets the expectations of different stakeholders, e.g., maximising the return on investment for the network operator, and to attain certain coverage, capacity, and quality of service for the subscribers. In view of the more sophisticated air-interface technologies and more stringent service requirements in the 5G era, the mid- and long-term NP process will be more challenging than those of older-generation networks.

The NP process can generally be divided into three phases: pre-planning or network dimensioning; detailed network planning; and post-deployment optimisation [4]. The output of the network dimensioning phase provides an approximate number of cell sites required to cover an area of interest. The detailed planning phase, which is usually the most expensive and complicated phase, is carried out using proprietary software and detailed terrain data to determine the actual locations and parameters of the BSs within the area to be served. The last phase is performed after the network has been deployed and operational, whereby the network performance is continually monitored, analysed, and improved.

As 5G roll-out gains traction throughout the world, the digital-skill gap of talents is widening fast, thereby posing a major challenge across the telecommunication industry in attracting new as well as upskilling talents with the expertise to plan, deploy, operate and maintain the continually evolving mobile cellular networks [5-8]. Investing in talent development by the telecommunication industry is key to fill the 5G skills gap [9, 10]. In recent years, curricula related to cellular network planning and optimisation have been introduced at universities and training institutions. However, the form of learning is largely passive in nature, relying on listening to instructors and memorization of facts and figures. One of the main reasons is due to the lack of practical learning tools for effective teacher-learner interactions. Grasping the underlying principles of this subject is often difficult due to the complex interrelationships and high dimensions of the many factors and parameters involved in the network planning process. This phenomenon is even more evident in the 5G era due to the sophistication of 5G technology.

Beginning from the 3G era, considerable effort has been made to develop RAN dimensioning tools. Li [11] presented innovative analytical models and algorithms for dimensioning 3G RANs. The analytical dimensioning models were implemented into a commercial dimensioning tool which can be used to help 3G network operators to reduce network costs while achieving the desired quality of service. Upase et al. [12] introduced an in-house developed analytical dimensioning tool called DoORs, which facilitates quick and accurate dimensioning of 4G Worldwide Interoperability for Microwave Access (WiMAX) networks. Hussein et al. [13] developed a 4G Long Term Evolution (LTE) network dimensioning tool using Java, which only considers one type of propagation model. Ibrahim et al. [14] developed a similar LTE network dimensioning tool using C# programming. Acakpovi et al. [15] implemented an LTE dimensioning tool that considers a variety of propagation models using Visual Basic. El-Din and Fayed [16] developed another LTE dimensioning tool using MATLAB. Nevertheless, these LTE dimensioning tools are only applicable to 3G and 4G networks and none of them are made accessible to the public for ubiquitous online learning. On the other hand, similar network dimensioning tools for 5G networks remain unexplored largely due to the high complexity of 5G RANs. To date, the only online tools available for 5G network pre-planning are restricted to simple link budget and throughput calculators using selected path loss models, examples include [17, 18]. Consequently, the general lack of interactive educational tools has been a limiting factor to facilitate active learning of 5G network pre-planning.

The current work aims to reduce this digital-skill gap by developing a 5G RAN dimensioning (5G-RAND) tool for enhanced learning by encompassing interactivity. The literature provides evidence that interactive tools can be effective in facilitating student learning, understanding of concepts, retention of information, and improving test scores [19]. More importantly, the 5G-RAND tool developed has also been made available in the public domain [20], enabling learners across the globe to gain hands-on experience in 5G network pre-planning through engagement and exercises.

2. 5G NR physical layer overview

This section provides a brief overview of the 5G NR physical layer critical to 5G network dimensioning, with an emphasis on the key differences with respect to 4G LTE.

2.1. 5G spectrum and duplexing schemes

To fulfil the requirements of massive connections and ultra-high data rates, new frequency bands above 24 GHz have been specified to complement the frequency bands below 6 GHz. The frequency range of 0.45–7.125 GHz is commonly referred to as frequency range 1 (FR1), while the range 24.25–52.6 GHz is known as FR2. Different frequency bands exhibit different characteristics and are divided into low, medium, and high frequency bands to serve different purposes. Low-frequency bands correspond to frequency bands below 2 GHz, and often used to provide a coverage layer for wide and deep coverage, including indoors, due to their good radio propagation characteristics. For early deployment, the 600 – 700 MHz band is of global interest with a maximum channel bandwidth of 20 MHz [21].

Medium-frequency bands are in the range of 2–6 GHz and can provide intermediate coverage, capacity, as well as high data rates through a wider channel bandwidth of 100 MHz. The range 3300–4200 MHz is of global interest, with some regional variations. Lastly, high-frequency bands in the millimetre wave (mmWave) range above 24 GHz are susceptible to signal degradation, but they give access to wider bandwidths up to 400 MHz or even higher through carrier aggregation. For this reason, they are most suitable for small-cell hotspot coverage with very high capacity and throughput demands [21].

For cellular systems, it is necessary to send data in both directions simultaneously. A duplexing scheme refers to the way uplink (UL) and downlink (DL) data transmission are separated. Both paired bands, where separate frequency bands are allocated for UL and DL, and unpaired bands with a single frequency band shared for UL and DL, are included in the NR specifications. For lower-frequency bands, paired bands are normally used to implement frequency division duplexing (FDD), while at higher-frequency bands, unpaired bands typically are used for time division duplexing (TDD) [21].

2.2. Transmission scheme and frame structure

Similar to LTE, NR uses orthogonal frequency-division multiplexing (OFDM) as the baseline transmission scheme due to its robustness to channel fading and ease of exploiting multiuser diversity. However, unlike LTE which uses a fixed subcarrier spacing of 15 kHz, NR supports a flexible OFDM numerology (i.e., subcarrier spacing and symbol length) for more flexible deployments covering a wide range of services and subcarrier spacings ranging from 15 kHz up to 240 kHz. A smaller sub-carrier spacing provides a longer cyclic prefix which is needed in large cells to address time dispersion, whereas a higher subcarrier spacing is needed in small cells to handle the increased phase noise at higher frequency bands.

In NR, multiple OFDM symbols are used to construct slots, subframes, and frames. A slot consists of 14 OFDM symbols for the given sub-carrier spacing, a subframe is defined as a 1 ms interval, and 10 subframes constitute a frame. The detailed relationships between different numerology are shown in Table 1. Unlike

LTE which uses two different frame structures, NR uses a common frame structure regardless of the duplexing mode.

Parameter / Numerology	0	1	2	3	4
Subcarrier spacing (kHz)	15	30	60	120	240
OFDM symbol duration (µs)	66.67	33.33	16.67	8.33	4.17
Cyclic prefix duration (µs)	4.69	2.34	1.17	0.57	0.29
OFDM symbol duration including cyclic prefix (µs)	71.35	35.68	17.84	8.92	4.46
Frequency band (GHz)	< 6	< 6	< / > 6	> 6	> 6
Number of OFDM symbols per slot	14	14	12 / 14	14	14
Number of slots per 1 ms subframe	1	2	4	8	16
Number of slots per 10 ms frame	10	20	40	80	160

2.3. Modulation and coding schemes, transport block size, and throughput calculation

The smallest physical resource in NR is called a resource element (RE), which uses one subcarrier during one OFDM symbol. Furthermore, 12 consecutive subcarriers in the frequency domain form a resource block (RB). The widest NR carrier carries 275 RBs, which corresponds to 3300 subcarriers and gives the largest possible carrier bandwidth for each numerology. However, the per-carrier bandwidth is limited to 400 MHz, resulting in the maximum carrier bandwidths of 50/100/200/400 MHz for subcarrier spacings of 15/30/60/120 kHz, respectively [21].

A modulation scheme defines the numbers of useful bits that can be carried by one symbol. In 4G and 5G systems, a symbol is carried by one RE. In addition to quadrature phase shift keying (QPSK), 16-quadrature amplitude modulation (16-QAM), 64-QAM which are previously defined in LTE, NR additionally supports 256-QAM modulation. Moreover, a modulation scheme is normally used in conjunction with a forward error correction scheme of a certain code rate to provide error correction capability, thus forming a modulation and coding scheme (MCS). A total of 29 MCSs have been defined in NR, which can be deployed to best suit the radio signal quality.

The transport block size (TBS) defines the number of bits the medium access control layer transfers to the physical layer per transmission time interval. In 4G LTE, the transport block size is chosen from a table using several parameters, namely the MCS index, the number of RBs, and the TBS index [22]. However, determining TBS in 5G NR is more complicated due to the use of different OFDM numerologies. In 5G NR, the TBS is determined using a formula-based approach combined with a table for the smallest TBS [1].

Two approaches can be used to estimate the achievable throughput resulting from the use of a specific MCS scheme. The first approach uses the formula specified in [2], which is based on the highest MCS scheme, hence it tends to overestimate the throughput achievable in practice. On the one hand, the second approach introduced in [23], which is based on TBS and is more accurate, is adopted in the 5G-RAND tool.

2.4. 5G radio channel modelling

Channel models are used to predict the mean received signal power at different locations within a coverage area. For efficient 5G network planning and optimisation, there is a need for new channel models which can accommodate the higher frequency bands and larger antenna arrays currently not addressed by existing channel models developed for earlier generations of cellular networks. The 5G-RAND tool adopts the 5G non-light-of-sight channel models described in [3].

3. Methods

This section presents the design principles of the 5G-RAND tool.

3.1. High-level design of 5G-RAND

The main objective of network dimensioning is to obtain an estimation of the number of cell sites required to satisfy the coverage and capacity requirements. This dimensioning process requires constant optimisation and tuning of parameters to cope with the varying subscriber scale and user profiles. Although the process does not lead to the final network deployment plans or more detailed site distributions, it is essential in order to give a realistic understanding of the capital and operational expenditures.

A high-level design of the 5G-RAND tool is depicted in Fig. 2, which has been developed based on 3GPP technical specifications [1-3] using Microsoft Excel spreadsheets. The tool allows network planners to first define their goals, including projected market share, type of service area, subscriber scale, coverage

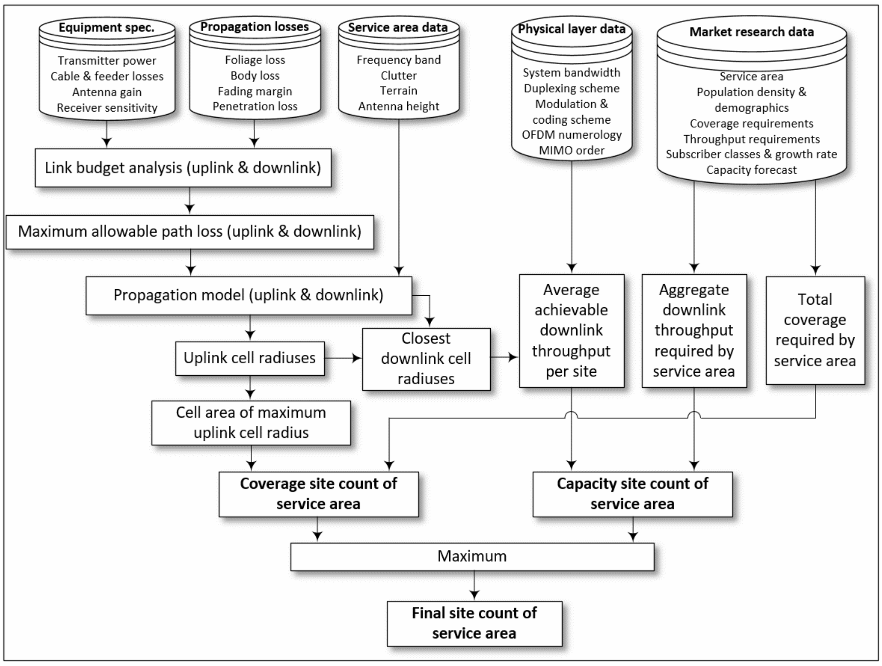


Fig. 2. High-level design of the 5G-RAND tool.

and throughput requirements, etc. Since the number of factors affecting the 5G network dimensioning process is very high, the 5G-RAND tool is designed to be interactive, allowing network planners to track, analyse, observe and display the dimensioning outcomes by tinkering with different network requirements, equipment specifications, channel conditions, etc.

3.2. Information gathering

To begin with, it is essential to gather a slew of technical and non-technical information. The former includes equipment specifications (e.g., transmitter power, cable and feeder losses, antenna gain, receiver sensitivity) which can be obtained from equipment vendors, various propagation losses (e.g., foliage loss, body loss, fading margin, penetration loss) which can be acquired from field measurements, as well as service area data (e.g., frequency band, clutter, terrain, antenna height) and physical layer data (e.g., system bandwidth, duplexing scheme, MCS, OFDM numerology).

The non-technical information required primarily refers to some market research data in terms of the type of service area (e.g., rural or urban), coverage requirements (e.g., incremental or full coverage), population density and projected market share, average single user's throughput requirements considering a mixture of various traffic (e.g., web browsing, social media, online games, video streaming), subscriber growth rate, future traffic forecast, etc. For learning purposes, artificial or typical values based on assumptions can be used if real information is not available.

3.3. Coverage site count

Coverage is related to the coverage areas, service probability, and related signal strength to provide connectivity. The market research data can be utilized to calculate the total coverage required by each service area. To obtain the coverage site count of a service area, it is essential to first perform link budget analysis. A link budget is the calculation of the total gain and loss in the signal strength of the link between the mobile station (MS) antenna and the BS antenna. The information used for link budget calculations includes equipment specifications and various propagation losses. The result of the link budget calculations for both the UL and DL is the maximum allowable path loss (MAPL), from which the feasible UL and DL cell radius can be deduced using a propagation model suitable for the target service area and frequency band.

Nevertheless, since the power transmitted by the MS antenna is generally less than that of the BS antenna due to battery energy constraints, the UL power budget is more critical than the DL power budget [4]. As a result, link budget analysis based on the UL will be used to determine the cell radius or coverage area, and thus the coverage site count. However, since each individual MCS dictates a separate link budget calculation and results in a separate cell radius, there will be as many link budgets as the number of MCSs.

Therefore, to achieve reasonable dimensioning accuracy without excessive complexity, we assume that all subscribers are uniformly distributed within a cell while limiting the maximum number of MCSs deployed within the cell at once to six for both UL and DL. In other words, the six MCSs intended to be used ranging from the cell centre to the cell edge are to be selected during the dimensioning process. Consequently, the lowest-order (albeit the most robust) MCS selected will give the maximum UL cell radius from the link budget analysis, which is then used to calculate the cell area. The ratio of the total coverage area required to the cell area gives the coverage site count of the service area.

3.4. Capacity site count

Capacity is related to the system capability for sustaining a certain number of subscribers and throughput. As opposed to coverage dimensioning, capacity dimensioning is often dominated by the DL due to the fact that mobile users download more than they upload. As a matter of fact, the peak hour use requires significantly more capacity than during off-peak hours. Moreover, each subscriber profile typically encompasses a mixture of various data traffic, resulting in different throughput requirements. Therefore, the cost efficiency of an over-dimensioned network will be low due to the too costly (albeit high-quality) deployment. To this end, the 5G-RAND tool developed allows the network planner to incorporate the average hour use and activity factor in such a way that the capacity demands can still be coped with satisfactorily. Using the market research data, the average DL throughput required by each subscriber can be estimated, from which the aggregate average DL throughput required by the entire service area can be calculated (i.e., by multiplying the average DL throughput required by each subscriber by the total number of subscribers within the service area).

Next, information related to the 5G NR physical layer can be used to estimate the average achievable DL throughput per site. Note that subscriber distribution will impact the average cell throughput, therefore we follow the same assumption made for coverage dimensioning, i.e., all subscribers are uniformly distributed within a cell. However, this estimation task is complicated by the fact that there are up to 29 MCSs which can be deployed on the DL, with each representing a certain spectral efficiency (measured in the number of information bits per modulation symbol) [1]. In principle, the MCS to be selected for a device is based on the measured signal-to-noise ratio. In general, subscribers located near the cell edge require a lower-order MCS, which leads to a lower throughput, or they will experience unacceptable link quality. On the other hand, subscribers located closer to the BS will be scheduled to use a higher order MCS, thereby achieving a higher throughput.

As both capacity and coverage are interrelated, the MCSs assumed in capacity dimensioning cannot be chosen arbitrarily and independently. Instead, the DL cell radius resulting from the deployment of a particular MCS should be similar to the UL cell radius obtained in coverage dimensioning, thereby attaining similar UL and DL transmission ranges for duplex communications. With this in mind, the six UL cell radiuses obtained from coverage dimensioning will be used to identify the six corresponding closest DL cell radiuses (out of the 29 cell radiuses). After obtaining these DL cell radiuses, the respective underlying MCSs can be retrieved from the DL link budgets. The average achievable DL throughput per site can then be calculated by aggregating the six weighted throughputs, each of which is the product of individual achievable throughput arising from the MCS and corresponding per cent coverage area. Subsequently, the capacity site count of the service area can be estimated by dividing the aggregate DL throughput of the service area by the average achievable DL throughput per site.

3.5. Estimation of future site counts

The dimensioning process yields the theoretical coverage and capacity site counts; these two numbers are normally different from each other. Some areas are predominantly coverage driven, e.g., green fields or rural areas with low subscriber numbers, while densely populated regions dominated by a large subscriber base with heavy traffic usages are capacity driven. In order to fulfil both the capacity and coverage requirements, the larger of the two will be taken as the final site count for a particular service area. Generally, during the initial deployment phase, the coverage site count tends to be larger than the capacity site count, implying an oversupply of capacity to achieve the desired coverage.

At some point in the future, as subscriber number and traffic demands increase, the capacity site count will overtake the coverage site count. Therefore, it is necessary to plan capacity ahead in the mid- and long-term to avoid the network performing badly due to capacity demand outstripping the network capacity. The 5G-RAND tool can be used to project the network size over a five-year period based on forecasts of mobile coverage, subscriptions, and traffic.

3.6. 5G-RAND interface design and interactive e-learning platform

The 5G-RAND tool has been developed using Microsoft Excel spreadsheets to facilitate the complex calculations required in 5G RAN dimensioning. Its interface contains four tabs: The User Guide tab, the Physical Layer & Throughput tab, the Advanced Link Budget tab, and the Capacity & Coverage Site Counts tab. The User Guide tab gives the instructions that help users to understand the usage of each tab. The Physical Layer & Throughput tab allows users to specify the physical layer data and obtain the achievable throughput for different MCSs based on their sensitivity levels.

The Advanced Link Budget tab allows users to provide equipment specifications, propagation losses, and service area data. For each service area, users are also required to choose the six MCSs through pull-down menus, ranked from the highest to the lowest order, to be deployed on the UL. The six UL cell radiuses obtained from link budget calculations will be used to identify the six corresponding closest DL cell radiuses and MCSs. The largest UL cell radius and the average DL capacity per site obtained will be used for subsequent estimation of site counts.

Lastly, the Capacity & Coverage Site Counts tab is designed to determine the capacity and coverage site counts according to all the information provided, including forecasts of mobile coverage, subscriptions, and traffic demands. The interactive feature of the 5G RAND tool lies in its ability to instantly calculate and display the dimensioning result, making it easier to learn the complex process of 5G network pre-planning. In addition, the 5G-RAND tool has been converted into an online e-learning platform [20], thereby enabling learners across the globe to engage in interactive learning of 5G network pre-planning at their own pace.

4. Results and Discussion

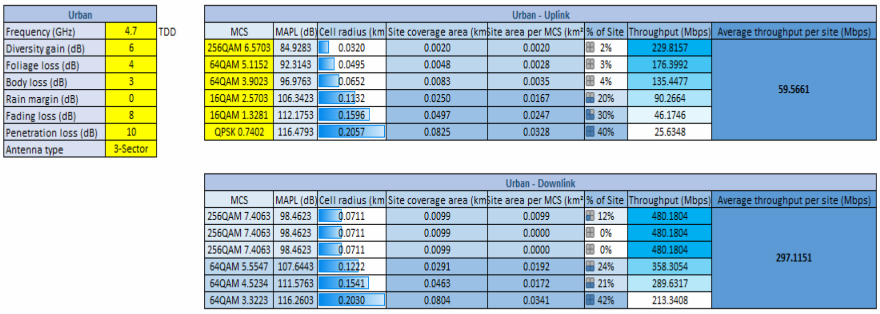
4.1. 5G network dimensioning examples

This section presents some 5G dimensioning results obtained using the 5G RAND tool based on the scenario parameters shown in Table 2. For simplicity, four types of subscriber with the following monthly data usage and percentage of subscribers are considered for all types of area: very heavy (30 GB, 35%), heavy (20 GB, 40%), medium (7 GB, 20%), and light (3 GB, 5%).

Table 2 Sample parameters used in the 5G-RAND tool.

Parameter	Dense urban	Urban	Suburban	Rural
Total area (km²)	10000			
Total population	3000000			
Addressable market (%)	65%			
Market share in Year 1 (%)	20%			
Number of subscribers	89700	17500	11700	7800
Total capacity demand (Mbps)	456984	841505	525941	32725
Coverage per service area (km²)	300	1500	3500	4700
Frequency (GHz)	28	4.7	2.6	0.7
Uplink MCSs	256-QAM, 64-QAM, 16-QAM,QPSK		64-QAM, 16-QAM, QPSK	64-QAM, 16-QAM
Downlink MCSs	256 QAM, 64 QAM			
Duplexing mode	TDD	TDD	FDD	FDD
Channel bandwidth (MHz)	50	50	30	30
Subcarrier spacing (kHz)	60	60	30	30
Antenna type	3-Sector	3-Sector	3-Sector	Omnidirectional

Figure 3 shows the results obtained from the Advanced Link Budget tab for the urban area, displaying the MAPLs, cell radiuses, and average throughputs calculated based on the six UL MCSs chosen. In this example, the largest UL cell radius of 0.2057 km and the average DL capacity per site of 297.12 Mbps will be used for estimating the coverage and capacity site counts required. Next, the coverage and capacity requirements are specified over a 5-year period in the Capacity & Coverage Site Counts tab using the forecasts shown in Table 3; the corresponding projected number of subscribers and downlink traffic demand for different service areas are obtained as shown in Fig. 4. These projections over a 5-year period for different types of service areas are obtained according to their respective forecast subscriber and traffic growth rates specified in Table 3 (i.e., as part of the market research data).



Urban		
Frequency (GHz)	4.7	TDD
Diversity gain (dB)	6	
Foliage loss (dB)	4	
Body loss (dB)	3	
Rain margin (dB)	0	
Fading loss (dB)	8	
Penetration loss (dB)	10	
Antenna type	3-Sector	

Urban - Uplink

MCS	MAPL (dB	Cell radius (km	Site coverage area (km	ite area per MCS (km²	% of Site	Throughput (Mbps)	Average throughput per site (Mbps)
256QAM 6.5703	84.9283	0.0320	0.0020	0.0020	2%	229.8157	59.5661
64QAM 5.1152	92.3143	0.0495	0.0048	0.0028	3%	176.3992	
64QAM 3.9023	96.9763	0.0652	0.0083	0.0035	4%	135.4477	
16QAM 2.5703	106.3423	0.1132	0.0250	0.0167	20%	90.2664	
16QAM 1.3281	112.1753	0.1596	0.0497	0.0247	30%	46.1746	
QPSK 0.7402	116.4793	0.2057	0.0825	0.0328	40%	25.6348	

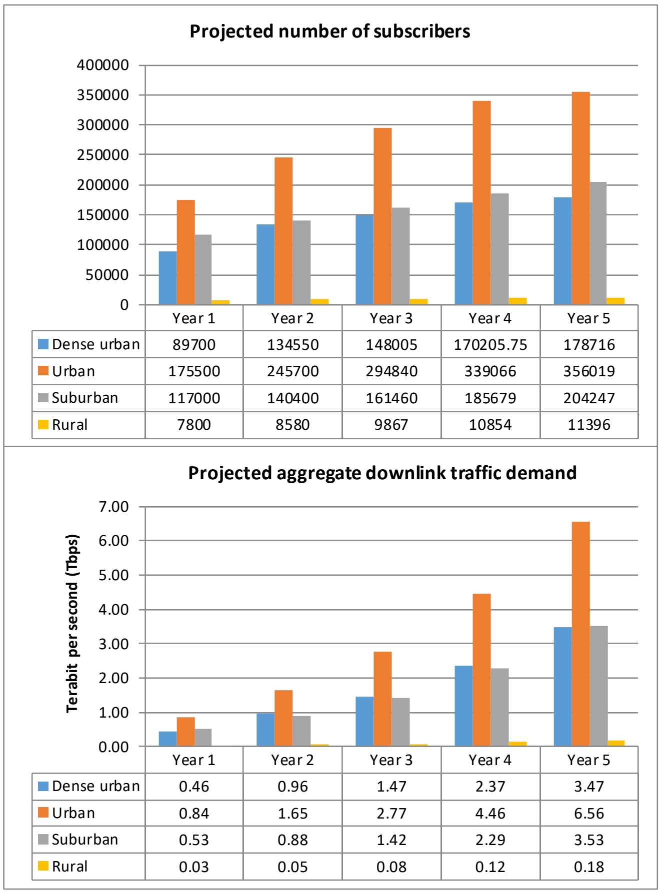
Urban - Downlink

MCS	MAPL (dB	Cell radius (km	Site coverage area (km	ite area per MCS (km²	% of Site	Throughput (Mbps)	Average throughput per site (Mbps)
256QAM 7.4063	98.4623	0.0711	0.0099	0.0099	12%	480.1804	297.1151
256QAM 7.4063	98.4623	0.0711	0.0099	0.0000	0%	480.1804	
256QAM 7.4063	98.4623	0.0711	0.0099	0.0000	0%	480.1804	
64QAM 5.5547	107.6443	0.1222	0.0291	0.0192	24%	358.3054	
64QAM 4.5234	111.5763	0.1541	0.0463	0.0172	21%	289.6317	
64QAM 3.3223	116.2603	0.2030	0.0804	0.0341	42%	213.3408	

Fig. 3. Output extracted from the Advanced Link Budget tap of the 5G-RAND tool for the urban area.

Table 3 Forecasts of mobile coverage, subscriptions, and traffic growth rates over a 5-year period.

Area / Year	1	2	3	4	5
Coverage requirements					
Dense Urban	70%	80%	90%	95%	100%
Urban	60%	75%	85%	95%	100%
Suburban	50%	65%	75%	80%	85%
Rural	30%	45%	55%	60%	65%
Capacity requirements					
Annual traffic growth rate	40%				
Annual subscriber growth rate					
Dense Urban	0%	50%	10%	15%	5%
Urban	0%	40%	20%	15%	5%
Suburban	0%	20%	15%	15%	10%
Rural	0%	10%	15%	10%	5%

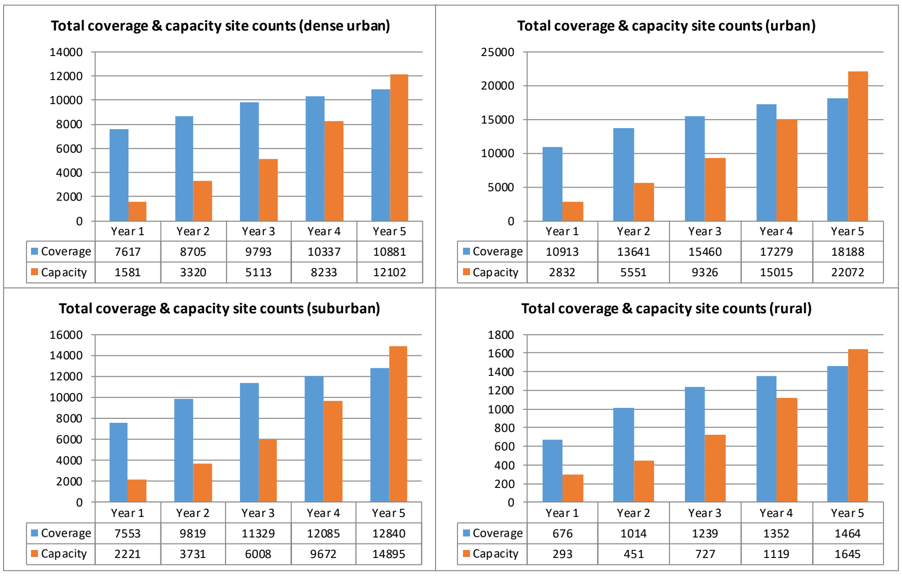


	Year 1	Year 2	Year 3	Year 4	Year 5
Dense urban	89700	134550	148005	170205.75	178716
Urban	175500	245700	294840	339066	356019
Suburban	117000	140400	161460	185679	204247
Rural	7800	8580	9867	10854	11396

	Year 1	Year 2	Year 3	Year 4	Year 5
Dense urban	0.46	0.96	1.47	2.37	3.47
Urban	0.84	1.65	2.77	4.46	6.56
Suburban	0.53	0.88	1.42	2.29	3.53
Rural	0.03	0.05	0.08	0.12	0.18

Fig. 4. Projected number of subscribers and downlink traffic demand for different service areas over a 5-year period.

Figure 5 shows the total site counts estimated by the 5G-RAND tool for different types of service area using all the assumed input data. The higher frequency bands used by the dense urban, urban, and suburban areas have the advantage of being able to achieve a higher throughput due to the abundant bandwidth. However, transmitting radio waves at higher frequencies incurs greater attenuation losses, hence resulting in smaller cell radiuses and hence higher coverage site densities. In contrast, although the rural area has the largest coverage area, it requires a significantly smaller number of coverage sites because a low-frequency band of 0.7 GHz, which is capable of achieving a larger transmission range, is deployed.


Total coverage & capacity site counts (dense urban)

	Year 1	Year 2	Year 3	Year 4	Year 5
■ Coverage	7617	8705	9793	10337	10881
■ Capacity	1581	3320	5113	8233	12102

Total coverage & capacity site counts (urban)

	Year 1	Year 2	Year 3	Year 4	Year 5
■ Coverage	10913	13641	15460	17279	18188
■ Capacity	2832	5551	9326	15015	22072

Total coverage & capacity site counts (suburban)

	Year 1	Year 2	Year 3	Year 4	Year 5
■ Coverage	7553	9819	11329	12085	12840
■ Capacity	2221	3731	6008	9672	14895

Total coverage & capacity site counts (rural)

	Year 1	Year 2	Year 3	Year 4	Year 5
■ Coverage	676	1014	1239	1352	1464
■ Capacity	293	451	727	1119	1645

Fig. 5. Total site counts estimated by the 5G-RAND tool over a 5-year period.

Moreover, it is observed that the coverage site counts for all service area types tend to flatten as time progresses because once the service area has been fully covered, there will be no need for additional sites. On the other hand, the capacity site count keeps growing due to the continued increase in subscribers and traffic demands. At some point, depending on the subscriber and traffic growth rates, the capacity site count will overtake the coverage site count and the focus shifts to optimizing the network capacity. Therefore, the 5G-RAND tool can be used to estimate the point at which the network engineers need to start focusing more on capacity than coverage.

4.2. Classroom experience

A total of 22 participants with diverse backgrounds, including network engineers, managers, solution architects and graduate students, have been exposed to use the 5G-RAND tool in an advanced cellular network planning short course conducted at Multimedia University. After lectures on the theory of RAN planning and dimensioning were delivered, a pre-test constituting 20 technical questions related to network dimensioning was conducted to assess the participants' comprehension of the subject. Two exemplary questions are: 1. "Which of the following factors will increase the number of cell sites needed to fulfil the coverage demands of a 5G network? Options: An increase in antenna's height; Deployment of smaller radio cells; A reduction in the total coverage area required; An increase in antenna's transmission power"; 2. "Which of the following factors will increase the MAPL in the downlink of a 5G network? Options: The gain of the base station's antenna is reduced; The use of lower order modulation schemes; The mobile phone is carried from an outdoor environment to an indoor environment; Channel fading loss is increased".

Following the pre-test, without releasing the answers, the 5G-RAND tool was then used to reinforce their understanding of the subject by allowing participants to dimension in person a 5G deployment area with a mixture of service area types using artificial data, similar to the example presented in Section 4.1. We observed that engaging participants in the interactive 5G-RAND learning platform greatly increases their interest and attention, motivates them to practice higher-level critical thinking, and builds good learning experiences. After the hands-on session, the participants were given the second attempt to answer the same set of questions in a pro-test. The evaluation results reveals that the interactive activity induced on this learning platform has significantly improved participants' mean score from 10.50 points to 16.95 points, where one point is given for correctly answering one of the 20 questions.

5. Conclusion and Future Work

This study has developed a standards-compliant 5G-RAND tool using Microsoft Excel spreadsheets, which can be used to facilitate active learning of the complex 5G network dimensioning process through an interactive interface. Unlike the existing online 5G network pre-planning tools, e.g., [17, 18], which can only perform simple link budget and throughput calculations, the 5G-RAND is a comprehensive 5G network dimensioning tool for a geographical area with a mixture of different types of service area (e.g., urban, sub-urban, rural). The tool uses the technical and non-technical information acquired by the network planners to obtain an approximate number of cell sites required to fulfil the coverage and capacity requirements. As both capacity and coverage dimensioning are interrelated, the coverage and capacity site count calculators are designed to interwork with each other, thus ensuring similar UL and DL transmission ranges for efficient duplex communications are achieved. More importantly, the tool has been made available to the public via an online platform, enabling learners across the globe to gain hands-on experience in 5G network pre-planning at their own pace. It is observed that introducing the 5G-RAND tool in the classroom greatly trigger learners' attention and interest in the subject while significantly improving their test scores. We believe that the 5G-RAND tool can help learners improve their skills in 5G network pre-planning while paving the way for studying advanced detailed network planning.

Nevertheless, there are some limitations in the 5G-RAND tool developed. For example, the tool has been designed for dimensioning of a homogeneous 5G network, i.e., a network that only employs one type of BS in a service area (e.g., urban or sub-urban). Future designs can be improved by enable dimensioning of heterogeneous 5G networks using a mixture of BSs of different transmit power and overlapping coverage in a geographical area with non-uniform distribution of subscribers. These require the development of more sophisticated subscriber distribution models, coverage and capacity site count calculators, and interference models. Further work should also incorporate more complicated and accurate propagation channel models into the tool, including those for indoor environments as indoor coverage becomes more important but also more challenging with 5G.

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