

Dimensioning Data Volume Capabilities for an LTE Channel and Factors that Impact Capacity Capabilities

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Abstract— Simulations and papers often refer to the number of simultaneously connected users an LTE channel can support when discussing capacity capabilities. This paper discusses additional methods that can be used to dimension LTE networks based on the data volume capabilities of an LTE channel. This approach has the advantage of being a fixed target that will remain stable for a long period of time. The methods discussed in this paper are designed to be scalable across multiple vendors, scalable to large networks, comprehensive of a wide variety of possible scenarios, and mesh well with other data sources such as marketing forecasts which are also often provided as expected total data volumes as opposed to number of connected users. Additionally, calculations have been validated against data from a commercially available network.

Index Terms—LTE capacity, LTE Data Volume, LTE performance.

I. INTRODUCTION

In the wireless industry, there is an ongoing need to analyze the capacity and efficiency of various technologies and features. Many methods often evaluate these items based on the number of simultaneously connected users that can be supported. This can be very effective in some cases but also has some draw backs. In LTE, the behavior of users and parameters can have a great impact on how many users can be supported. For example, simply changing a hold timer can increase or decrease the number of connected users. Using data volume, on the other hand, can tell us what the capacity limits of a sector are without having to account for individual user behavior. This gives a stable threshold over time regardless of most parameter settings. In this paper, we offer methods and equations that account for the largest contributing factors to deciding what the data volume capacity capabilities of an LTE sector are. In addition to the calculations, data from a commercially available network is offered to validate the accuracy of the predicted values from the proposed methods. These methods also have the added value of meshing well with marketing forecasts that are based in volume and simplifying the special event planning process.

II. PHYSICAL CHANNEL STRUCTURE

The first step to determining total data volume capability is to understand the physical channel structure. Table I, taken from 3GPP 36.213 [3], tells us how many bits can be

transferred per resource element (RE). This is helpful, but for this to be useful we need to know how many RE's there are in an LTE channel over some given time period.

TABLE I
MODULATION AND CODING RATES

CQI	MODULATION	BITS	CODING RATE x 1024	RATE	ACTUAL AVG BITS PER RE
1	QPSK	2	78	0.0762	0.1523
2	QPSK	2	120	0.1172	0.2344
3	QPSK	2	193	0.1885	0.377
4	QPSK	2	308	0.3008	0.6016
5	QPSK	2	449	0.4385	0.877
6	QPSK	2	602	0.5879	1.1758
7	16QAM	4	378	0.3691	1.4766
8	16QAM	4	490	0.4785	1.9141
9	16QAM	4	616	0.6016	2.4063
10	64QAM	6	466	0.4551	2.7305
11	64QAM	6	567	0.5537	3.3223
12	64QAM	6	666	0.6504	3.9023
13	64QAM	6	772	0.7539	4.5234
14	64QAM	6	873	0.8525	5.1152
15	64QAM	6	948	0.9258	5.5547

Let us consider a 5MHz channel for a one hour time period. We first look at a single physical resource block (PRB) in one transmission time interval (TTI) to determine how many RE's there will be per PRB. First off, each PRB in 1 millisecond of time has 12 subcarriers (SC) and 14 orthogonal frequency division multiplex (OFDM) symbols [4][2]. Here, we will assume that the physical downlink control channel (PDCCH) will take up three OFDM symbols. Additionally, 6 more RE's will be dedicated to reference symbols (RS) [4][2]. This will give 126 symbols per PRB per TTI that are allowed to transmit data. See figure 1.

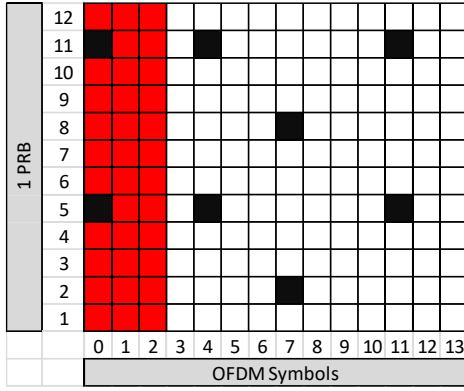


Fig. 1. Example of RE's available for data. White spaces are free to be used while others are overhead such as control plane and reference signal.

Since we are assuming a 5MHz channel, there will be 25 PRB's available in the frequency domain [4][2]. This means that per frame (10 milliseconds in time), there will be a total of 31,500 RE's available.

$$5\text{MHz} = 25 \text{ PRB's}$$

$$25 \text{ PRB's} * 126 \text{ RE's} = 3,150 \text{ RE's per subframe}$$

$$3,150 \text{ RE's} * 10 \frac{\text{subframes}}{\text{frame}} = 31,500 \text{ RE's per frame}$$

However, RE's dedicated to overhead are not yet accounted for. Sub-frame 0 utilizes the middle 72 RE's, 6 symbols wide for physical broadcast channel (PBCH), primary sync signal (PSS), secondary sync signal (SSS), etc. [4][2]. Sub-frame 5 utilizes the middle 72 RE's, 2 symbols wide for PSS and SSS [4][2]. This equates to an additional 576 RE's that are utilized for overhead. This leaves a total of 30,924 RE's available per frame to transmit data. This averages out to be 3092.4 RE's per sub-frame. The average number of RE's available per PRB is then 123.7.

$$(6 \text{ symbols} + 2 \text{ symbols}) * 72 \text{ RE's} = 576 \text{ additional RE's for overhead}$$

$$\frac{30,924 \text{ RE's}}{\frac{10 \text{ Frames}}{\text{Subframe}}} = 3092.4 \text{ RE's per subframe on average}$$

$$\frac{3092.4 \text{ RE's}}{25 \frac{\text{PRB's}}{\text{subframe}}} = 123.7 \text{ RE's per PRB per subframe, on average}$$

With the number of RE's available per PRB known, we can now consider how many PRBs are available for the bandwidth of interest and over what duration is being considered to arrive at a total volume capability. For example, for a 5MHz channel we must consider the frequency domain to be over 25 PRB's. In the time domain, 1 PRB covers one millisecond in time. This means for a one hour period, we must consider the time domain to cover 3,600,000 milliseconds. With these considerations, we can use table I to determine total volume expected using Eq. 1.

$$\frac{\frac{\text{Bits}_{\text{cqi}}}{\text{RE}} * \frac{123.7 \text{ RE's}}{\text{PRB}} * \# \text{ PRB's} * \# \text{ TTI's} * \frac{\text{Byte}}{8 \text{ bits}}}{\frac{\text{MB}}{1,000,000 \text{ Bytes}}} = \text{Total Volume/Time} \quad (1)$$

For example, for a CQI=9 on a 5MHz channel with our one hour period considered, total volume would be:

$$\frac{2.4063_{\text{cqi}=9}}{\text{RE}} * \frac{123.7 \text{ RE's}}{\text{PRB}} * 25 \text{ PRB's} * 3,600,000 \text{ TTI's} * \frac{\text{Byte}}{8 \text{ bits}} * \frac{\text{MB}}{1,000,000 \text{ Bytes}} = 3348 \text{ MB/HR}$$

However, there is more before we consider this the total volume capacity of a cell.

II. IMPACTS OF MIMO AND HARQ

The previous equation supplied is the underlying fundamental for calculating volume. However, this only tells us what the data volume capability is in one plane. LTE offers spatial multiplexing which allows for transmitting data in up to four planes when conditions allow. This means that in 2x2 MIMO (Multiple Input Multiple Output), the channel will be capable of transmitting twice as much data [4][2][1]. In 4x4 MIMO the channel will be capable of transmitting 4 times as much data [4][2][1]. Not all users can achieve 4x4 MIMO or even 2x2 MIMO so there will be a distribution of users that are able to achieve each condition. These conditions will vary from carrier to carrier and site by site. Therefore this must be accounted for on a case by case basis. Consider the example below in figure 2.

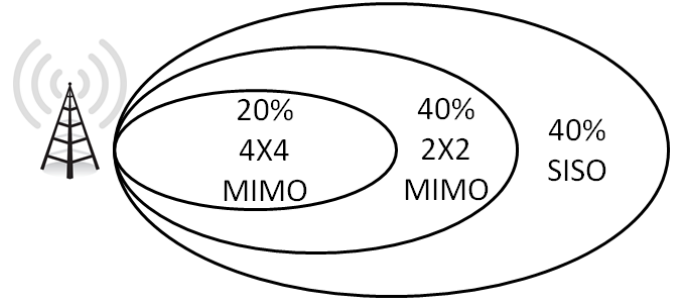


Fig. 2. Example distribution of MIMO/SISO usage.

In this example, we have 40% percent of the transmissions to be sent with SISO (single input single output), 40% in 2x2 MIMO, and 20% in 4x4 MIMO. To apply this information to the equation we developed previously, we must weight the total single layer volume by the percentage of traffic done under each condition. This is shown in Eq. 2

$$\text{Volume}_{\text{per layer}} [\% \text{SISO} + (\% 2 \times 2) * 2 + (\% 4 \times 4) * 4] = \text{Total Volume} \quad (2)$$

For example, in the case provided above using the same assumptions previously of 5MHz, CQI=9, and 1 hour, we have the following volume:

$$3348 \text{ MB} [40\%_{\text{SISO}} + (40\%_{2 \times 2} * 2) + (20\%_{4 \times 4} * 4)] \\ = 6696 \text{ MB/HR}$$

For design and planning purposes, it is a best practice to not design to 100 percent resource utilization. One can apply targeted PRB utilization thresholds to the volumes to provide a practical number with which to plan by. Each carrier may have different goals for performance and cost targets. In the example worked in this paper, if the target is to remain below 75% PRB utilization at all times so as to preserve other metrics such as throughput per user, the data volume on the cell cannot exceed 5022 MB per hour.

$$6696 \frac{\text{MB}}{\text{HR}} * 75\%_{\text{PRB Utilization}} = 5022 \text{ MB/HR}$$

Lastly, LTE operates at a targeted block error rate (BLER). Not all HARQ transmissions are acknowledged but they do require PRB resources [1][2]. To account for this, we must also multiply the above results by the expected HARQ rate. This can be assumed or measured from the network. In this case, let us assume that the expected HARQ success rate will be 90%. The final expected data volume capability becomes 4519 MB/HR.

$$5022 \frac{\text{MB}}{\text{HR}} * 90\% \text{ Success Rate} = 4519 \frac{\text{MB}}{\text{HR}}$$

II. VALIDATION

The above calculations assume that all transmissions are made with the same channel quality indicator (CQI) value. This of course is not what happens in a live network. Each cell will have a distribution of CQI values centered on an average CQI. Ideally, the traffic done at a higher than average CQI's will balance out the traffic done at lower than average CQI's.

Additionally, it is inherent that there will be rounding errors. To categorize each cell and apply table 7.2.3-1 from 3GPP 36.213, we must round the CQI values to an integer value. For example a cell with an average CQI of 8.51 will be rounded to an integer value of 9 as will a cell with an average value of 9.49. While these two cells are nearly a full CQI point different, they are categorized as the same in order to assign values from 3GPP 36.213.

Before one can use this as a planning value, it is important to compare the predicted results to actual values measured in the network to understand the expected errors of doing so.

To provide this validation, we collect samples from a live network with 5MHz cells and categorize each cell by the following factors:

- CQI
- Data Volume
- PRB Utilization
- MIMO/SISO distribution
- HARQ Success Rate

For each CQI group, we compare the measured value to the predicted value using the above method and show the results

in figure 3.

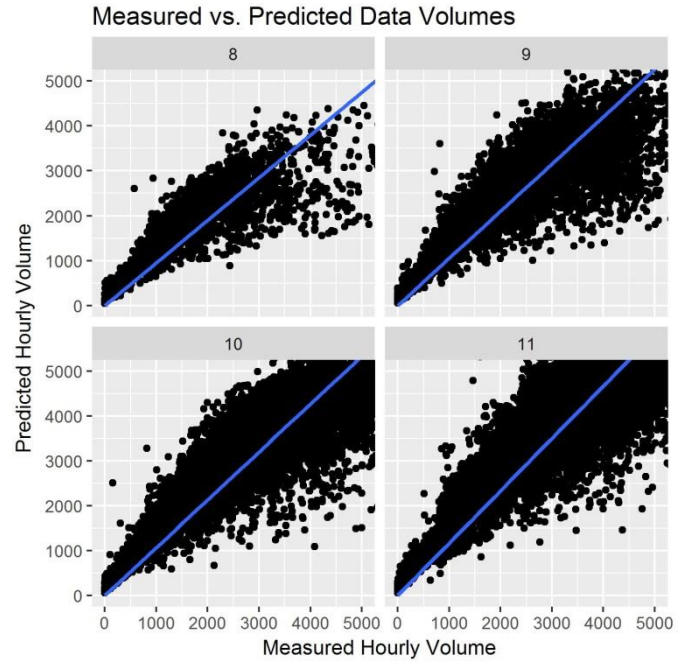


Fig. 3. Validated results of predicted volume calculations compared to the measured value from a live network.

II. ADDITIONAL INFLUENCING FACTORS

There are of course other factors that can impact the amount of data volume that can be transmitted. To account for these items would, however, require accounting for some complex topics that would be difficult to quantify on a case by case basis and overly complicate the planning process. Some of these could be:

- Inefficiencies in the PDCCH
- UL interference that causes increased PDCCH
- Scheduling limitations caused by hardware or air link limitations
- Unusual CQI distributions
- Feature and licensing limitations
- PRB's reserved for features such as location services which require positioning reference signals (PRS)

This is not an exhaustive list, but rather just a few of many different scenarios that can change volume capacity expectations.

If advanced tools, skill sets, and computing resources were available, one could even study the impacts that different CQI distributions would have on the volume capabilities of individual cells. Machine learning style techniques could also be applied to maintain dynamic models of each cells individual behavior over time compared to the whole network to find outlying performers that are less efficient than their counterparts so that they can be investigated and addressed where possible.

II. APPLICATION TO PLANNING

This method may be used for individual planning of targeted areas or for high level, long term forecasting.

For targeted venue planning, this method can be used in addition to other planning methods to dimension the number of nodes or bands required by making some simple assumptions. Let us take an example of an event where it is known that there will be 10,000 subscribers. If we assume that each subscriber will use 8.5 MB during the busy hour, then we know the system will need to be capable of handling 85,000 MB in one hour.

$$\frac{8.5 \text{ MB}}{\text{HR}} * 10,000 \text{ subscribers} = 85,000 \text{ MB/HR}$$

Using the same example provided previously, we know that each sector (5MHz, CQI=9) can support up to 4519 MB/HR and maintain 75% PRB utilization or less. To support this volume, a minimum of 19 cells would be required.

$$\frac{85,000 \text{ MB}}{5022 \frac{\text{MB}}{\text{Cell}}} = 18.8 \text{ Cells}$$

If 19 locations cannot be acquired to accommodate all 19 nodes, the desired capacity could be achieved by deploying 2 5MHz bands across 10 nodes to achieve a total of 20 cells. This would satisfy the minimum requirement.

The above method can also be applied to high level forecasting from any data source based on data volume using top down reconciliation processes. For example, a common exercise is to apply marketing data or roaming data forecasts to provide a future, high level outlook of capacity. These types of data are often very high level and not available at a per site level. The high level data can be distributed across the network and applied at a per site level. For example, one could start with company level data volumes that are distributed across geographical areas or markets by some weighting factor. From the market level, the data could then be distributed across the cells in the market. Calculated thresholds based on recent historical performance could then be applied to give an overall capacity view for varying marketing forecasts. See figure 4.

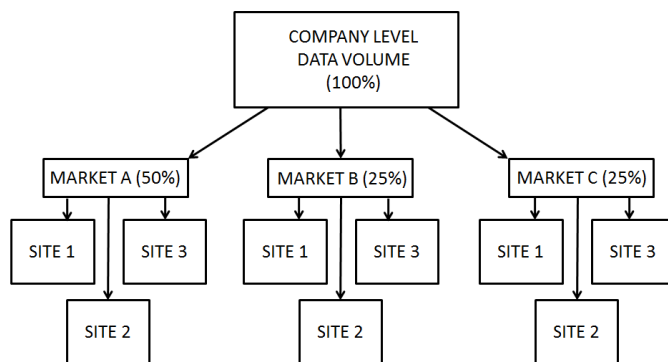


Fig. 4. Example of high level data volume forecasts distributed to site level where data volume thresholds can be applied.

REFERENCES

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Reggie Collette is a Lead RF Engineer for U.S. Cellular’s RF Engineering Team with over 15 years of design and optimization experience in the wireless industry. His role combines data analytics, RF design skills, and strategic visions to build forward looking strategies for the design and capacity of 4G and 5G networks. His previously held roles with U.S. Cellular include Sr. RF Engineer where he was focused on developing LTE capacity forecasting methodologies with big data, analytics based analysis of LTE network performance, and LTE/CDMA/EVDO RF design. Research interests include forecasting techniques, 4G and 5G advanced features, QoS strategies, network traffic call modeling, big data analytics, and other emerging radio technologies. Reggie holds a BS in electrical engineering from Iowa State University.