LTE MCS Cell Range and Downlink Throughput Measurement and Analysis in Urban Area

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Abstract. The measurement in this study was conducted using a TEMS Pocket engineering model test phone, through which the cell coverage and cell capacity of LTE were analyzed using the KPI parameters of packet switch (PS) between the 4G EnodeB base stations (BSs) and user equipment (UE). Of the 60 EnodeB BSs that were measured, 46 supported the 700 MHz band, 35 supported the 1800 MHz band, and 6 supported the 2600 MHz band. The analysis results for the measurement data showed that the modulation code scheme (MCS) cell range means for MCS (0)–MCS (28) in Banqiao District were approximately 0.2–0.91 km, with an overall MCS average of 0.45 km. Cell capacity was presented using downlink (DL) throughput; the analysis results illustrated that the average DL throughputs were roughly 5.37 Mb/s–49.71 Mb/s, and the overall MCS average throughput was 18.87 Mb/s. The signal-to-interference-plus-noise ratio (SINR) means for MCS (0)–MCS (28) were approximately −5.33–20.38 dB, and the overall MCS averaged SINR was approximately 6.04 dB. The reference signal received power (RSRP) means for MCS (0)–MCS (28) were approximately −111.86–−73.83 dBm, and the overall MCS averaged RSRP was approximately −94.09 dBm. Finally, the analysis and comparison of the theoretical values and actual measurement illustrated that the data curves for this study were consistent with the 3GPP specifications, with SINR and the theoretical curve achieving a correlation of up to 0.936, and the DL throughput and the theoretical curve achieving a correlation of up to 0.933.

Keywords: LTE · MCS · SINR · Cell range · Downlink throughput

1 Introduction

This study mainly focused on the practical 4G network use of Internet users in the densely populated Banqiao District in New Taipei City. In 2015, Chen et al. [1, 2] used an engineering model mobile phone equipped with Nemo Handy to analyze small scale fading and fast Ricean fading; moreover, they examined the BS traffic volume changes through big data in Kenting, Pingtung County [3].

In their study on the relationship between users and BS using a smart phone in 2016, Lehne et al. [4] noted that a site is divided into three sectors; however, their measurement

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data demonstrated that the distribution of users differs according to the BSs of the distinct bands they are connected to. The LTE 800 MHz users in this study were mainly distributed between the cell-centered range of −110°–50°, whereas those using 1800 and 2100 MHz were distributed between the cell-centered range of −60°–60°. From the perspective of spatial distribution, the density of users' distribution evidently declined as their distance from the BSs increased. A lower-frequency signal was capable of supporting a longer distance, with 800 MHz capable of reaching 1.62 km, whereas the distance was reduced to 580 m at 2100 MHz. In general, 90% of the users in the two case studies were located within a distance of 1.35–3.47 km from the BS.

In 2012, Sainju [5] conducted a study at Singerjärvi (66.069731°, 29.034217°) and Kumpuvaara (66.086234°, 28.481345°) in Kuusamo, Finland. Noting that Kuusamo belongs to a rural area, the study measured the three bands of LTE 800, LTE 1800, and UMTS 900 MHz from two BSs. The coverage area of the LTE 800 MHz BS at the Singerjärvi area had a maximum distance of up to 13.7 km, with a mean downlink (DL) throughput of 13.8 Mb/s, whereas a throughput of more than 10 Mb/s was achieved at a distance of 7.1 km. At the distance of roughly 11.8 km, the throughput further declined to 1 Mb/s. The coverage area for the LTE 800 MHz base area in the Kumpuvaara area had a maximum distance of 17.3 km with a mean DL throughput of 9.2 Mb/s. The throughput at 9.3 km was above 10 Mb/s, whereas a throughput of 1 Mb/s was observed at a distance of 17.3 km. The analyzed data revealed that lower-band signals were capable of greater coverage distances and had superior throughput.

The LTE signal strength can be directly determined through measurement; the enhancement or attenuation of reference signal receive power (RSRP) and signal-to-interference-plus-noise ratio (SINR) are correlated with channel quality indicator (CQI) and modulation code scheme (MCS) level [6]. The limits of cell edge and the possibility of improvement were also understood through the SINR and DL throughput in the measurement data.

The remainder of this study is organized as follows: Sect. 2.1 describes the measuring tools, methods, and routes; Sect. 2.2 describes the use of latitude and longitude as the conversion basis for the straight line distance between base station and user equipment (UE); and Sect. 2.3 introduces the calculation of the average KPI signal measured. Section 3.1 describes the distribution of the measured samples and the operation process between MCS level and CQI; Sect. 3.2 presents the overall data measurement analysis for all bands; and Sect. 3.3 illustrates the measurement data analysis results for each band (700, 1800, and 2600 MHz). Section 4 compares the measurement results with 3GPP specifications, and the results are illustrated in tables. Section 5 organizes the measurement results.

2 Measurement and Analysis Principle

2.1 Measurement Planning

This study used an engineering model phone equipped with the engineering model test software TEMS Pocket to measure the obtained the log files, and the parameter sampling and signal quality analysis were conducted using the Actix Analyzer software.

MCS, RSRP, SINR, information bandwidth (IB), and throughput were analyzed to provide a complete presentation of correlation analysis and to compare the theoretical and actual values for signal coverage.

Figure 1 shows the measurement route for Banqiao in New Taipei City. Lock mode was adopted for the network measurement. Thus, the 4G LTE 700-, 1800-, and 2600-MHz bands were locked, although specific BS were not locked during measurement.

Fig. 1. Measurement route for Banqiao, New Taipei City

2.2 GIS Distance Calculation

This study used a geographic information system (GIS), which is a digitized operating system capable of integrating relevant geographic information. The straight line distance between two points was calculated by combining geography and cartography. Because the calculation was conducted using the latitude and longitude of the Earth, spherical rather than planar coordinates were used. Latitude and longitude were used to calculate the distance between two points on a sphere, also known as the great circle distance, and its equation is as follows.

If the latitude and longitude for two points x and y are given by $(\emptyset_1, \lambda_1)$ and $(\emptyset_2, \lambda_2)$, the straight line distance d between the two points is calculated as follows (1):

$$d = R \times arccos(\sin\phi_1 \times \sin\phi_2 + \cos\phi_1 \times \cos\phi_2 \times \cos(\lambda_2 - \lambda_1)) \quad (1)$$

where R represents the radius of the Earth (6,378 km).

2.3 MCS Weighting Average Distance, SINR and DL Throughput Calculation

MCS samples as a weighting factor was included when calculating the essential parameter average for MCS levels, SINR, and DL throughput using (2), (3), and (4), in which the distribution function of MCS changes in the channel is considered.

(1) Average Distance:

$$D = \frac{\sum_{i=0}^{28} d_i \times n_i}{N} \tag{2}$$

where d_i represents the straight line distance corresponding to each MCS between the UE and EnodeB, n_i represents the corresponding sample for each MCS when the UE successfully connected to EnodeB, N is the total sample count of the successfully connect radio resource control, and D represents the average MCS distance.

(2) Average SINR:

$$SINR = \frac{\sum_{i=0}^{28} SINR_i \times n_i}{N} \tag{3}$$

where $SINR_i$ represents the corresponding SINR of each MCS between the UE and EnodeB, n_i represents the corresponding sample for each SINR when the UE was successfully connected to EnodeB, N represents the total sample count of the successfully connected RRC, and $SINR$ represents the average SINR of the MCS weighting.

(3) Average DL Throughput:

$$Tp = \frac{\sum_{i=0}^{28} Tp_i \times n_i}{N} \tag{4}$$

where Tp_i is the corresponding DL throughput for each MCS between the UE and EnodeB, n_i represents the corresponding sample for each MCS when the UE was successfully connected to EnodeB, N represents the total sample count of the successfully connected RRC, and Tp represents the average DL throughput for the calculated MCS level.

3 KPI Signal Analysis

3.1 MCS Index Profile

This chapter describes the analysis results for the measurement in Banqiao District in New Taipei City, Taiwan. The GIS theory mentioned in Sect. 2 was employed to calculate the distance between EnodeB and the UE. The MCS, SINR, DL throughput, RSRP, and relationships between the essential parameters of the LTE network, were presented with a series of broken line graphs. The corresponding MCS cell range, SINR, DL throughput, and RSRP were observed at different MCS levels. The measured data were then compared with the 3GPP theoretical values in Sect. 4.

The sample numbers determine the accuracy of the data and the actual situation of sample distribution during the data analysis and comparison. More than 110 000 samples were measured in this study, with each band including tens of thousands of test samples. Of the 60 BS that were measured, 46 supported the 700 MHz channel, 35 supported the 1800 MHz channel, and 6 supported the 2600 MHz channel. The sample distribution function indicates that the sample rose rapidly from MCS (6) and that most samples fell between MCS (6) and MCS (19) (more than 4000 samples for each level). The spectral efficiency was in the range of 0.877–3.029. The figure indicates that by constructing 4G LTE BSs, network operators enabled most users to use modulation technology above MCS (6). The test was conducted in an intense city.

3.2 All Band Signal Analysis

Figure 2 displays the measured SINR against the MCS cell range; the horizontal axis represents the MCS level, the blue line represents the corresponding principle coordinates for the MCS cell range values, and the red line represents the corresponding sub coordinates for the SINR values (unit: dB). The cell range means of MCS (0) to MCS (28) were in the range of 0.91–0.19 km, and the mean overall MCS was 0.45 km. The corresponding mean SINRs for each MCS from MCS (0) to MCS (28) were in the range of −5.33–20.38 dB, whereas the mean overall MCS SINR was approximately 6.04 dB. The curve changes of measured SINR and MCS cell range were almost linear with a correlation of −0.886, indicating that a more satisfactory MCS level was obtained with an improvement in SINR following a shorter distance to the BSs [7]. The average SINR value of MCS (0) was superior to those of MCS (1) and MCS (2). Because fewer samples were lower than MCS (4), the accuracy differed from the theoretical values.

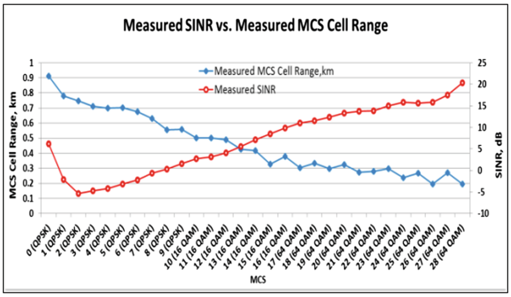


Fig. 2. Overall measurement of SINR for MCS (0)–MCS (28) vs. MCS cell range for each MCS level in Banqiao District (Color figure online).

Figure 3 shows the measured DL throughput against the MCS cell range. The horizontal axis represents the MCS level, the blue line is the corresponding principle coordinates for the MCS cell range values (unit: km), and the green line is the corresponding sub coordinates for the measured DL throughput values (unit: Mb/s). The average DL throughputs for each MCS from MCS (0) to MCS (28) were in the range of 22.91–49.71 Mb/s, with an average total MCS DL throughput of 18.87 Mb/s. The curves for the corresponding distance of each MCS and the measured DL throughput

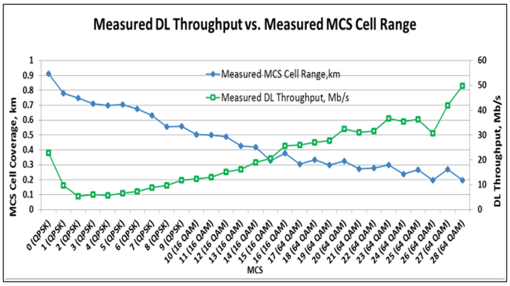


Fig. 3. Overall measurement of DL throughput for each MCS level from MCS (0) to MCS (28) vs. the MCS level in Banqiao District. The sub coordinates represent the DL throughput (Mb/s) measured in Banqiao District. The curves for the corresponding distance (Blue line) of each MCS and the measured DL throughput (Green line) had a correlation of −0.814 (Color figure online).

had a correlation of −0.814, revealing a significant negative correlation. The data indicated that a shorter distance to the BS led to a rise in SINR. This yielded a more satisfactory modulation method with a superior transmission efficiency, which resulted in an increase in the number of bits transferred per second and also enhanced the DL throughput. Figure 3 shows that the DL throughput performance of MCS (0) reached 22.91 Mb/s, which was higher than those of MCS (1) and (2), possibly because fewer samples were lower than MCS (4), thus causing the accuracy to differ from the theoretical values.

In addition, Fig. 4 compares the RSRP and SINR. The horizontal axis represents the MCS level, the purple line represents the corresponding principle coordinates for the RSRP values (unit: dBm), and the red line represents the sub coordinates for the SINR values (unit: dB). The RSRPs for MCS (0)–MCS (28) were in the range of −106.9 to −73.83 dBm, and the average RSRP was approximately −94.09 dBm. The SINR means for each MCS from MCS (0) to MCS (28) were in the range of −106.9 to −73.83 dBm, and the average overall MCS SINR was 6.04 dB.

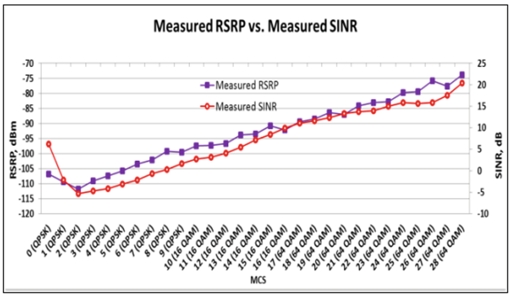


Fig. 4. Overall measurement of RSRP for each MCS level from MCS (0) to MCS (28) vs. SINR in Banqiao District. The sub coordinates represent the mean SINR (dBm) for the MCS level. The data revealed a positive correlation between RSRP (Purple line) and SINR (Red line) of up to 0.962 (Color figure online).

The data revealed a positive correlation between RSRP and SINR of up to 0.962. The performances of RSRP and SINR for MCS (0) were superior to those for MCS (1) and MCS (2), possibly because fewer samples were lower than MCS (4), causing the accuracy to differ from the theoretical values.

3.3 Individual Band Signal Analysis

Figure 5 illustrates the variations of SINR and MCS cell range. The horizontal axis represents the MCS level, the red line represents the corresponding principle coordinates for the MCS cell range (unit: km), and the blue line represents the corresponding sub coordinates for SINR (unit: dB).

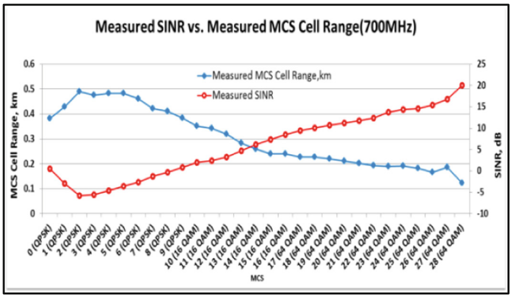
(a) The corresponding cell range means for each MCS from MCS (0) to MCS (28) under the 700-MHz band were approximately 0.38–0.12 km, and the overall MCS average was 0.31 km. The corresponding SINR means for each MCS between MCS (0) and MCS (28) were in the range of 0.50–20.06 dB, and the overall MCS SINR mean was 5.04 dB. The correlation between the changes in the corresponding distance of each MCS and SINR was −0.981, displaying a significant negative correlation.

(b) The corresponding cell range means for each MCS from MCS (0) to MCS (28) under the 1800 MHz band were in the range of 0.3 km to 0.25 km, and the overall MCS average was 0.26 km. The corresponding SINR means for each MCS between MCS (0) and MCS (28) were in the range of −3.88–21.81 dB, and the overall MCS SINR mean was 6.19 dB. The changes of the corresponding distance for each MCS and SINR had a correlation of-0.840, indicating a significant negative correlation.

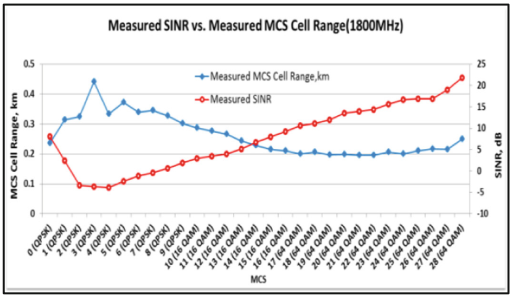
(c) The corresponding cell range means for each MCS from MCS (0) to MCS (28) under the 2600 MHz band were in the range of 1.17–0.52 km, and the MCS average was 0.96 km. The corresponding SINR means for each MCS between MCS (0) and MCS (28) were between 7.00 and 20.88 dB, and the overall MCS SINR mean was 5.71 dB. The correlation between the changes of the corresponding distance for each MCS and SINR was −0.967, demonstrating a significant negative correlation.

The average MCS distances for the 700-, 1800-, and 2600-MHz bands in this measurement data analysis were approximately 0.31, 0.26, and 0.96 km, respectively. According electromagnetic theory, a lower frequency for the 700-MHz band yields lower attenuation, which should result in greater coverage. However, the measurement data indicated that the coverage distances for the 700-, 1800-, and 2600-MHz bands did not match the theoretical estimation, possibly because the BSs of the 700- and 1800-MHz bands were more densely deployed in the urban area than those of the 2600-MHz band, thus reducing the coverage distance. The 2600-MHz band is a newly deployed band with fewer BSs in the urban area. Table 1 lists the number of BSs for each band deployed in the urban area.

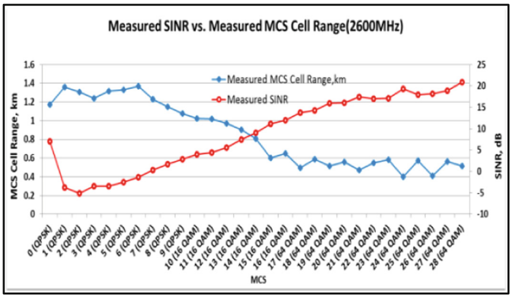
Moreover, the measurement data indicated that the MCS level and SINR had a significantly negative correlation. Thus, a shorter distance to the BS yielded a higher SINR, a larger MCS level used by UE, and a higher transmission efficiency, and vice versa.



(a) LTE 700MHz



(b) LTE 1800MHz



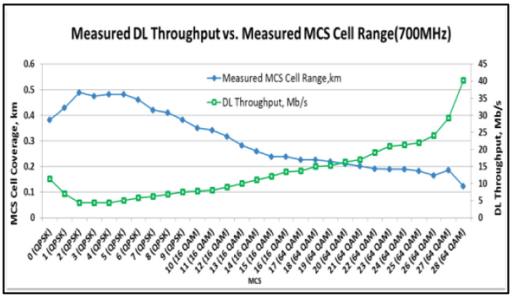
(c) LTE 2600MHz

Fig. 5. Overall measurement of SINR for MCS (0)–MCS (28) vs. MCS cell range corresponding to the MCS levels of each band in Banqiao District. The sub coordinates represent the mean SINR (dB) for each MCS level. (a) LTE 700 MHz, (b) LTE 1800 MHz, and (c) LTE 2600 MHz. The correlation between the changes in the corresponding distance of each MCS and SINR was −0.981 (a), -0.840 (b), and −0.967 (c) (Color figure online).

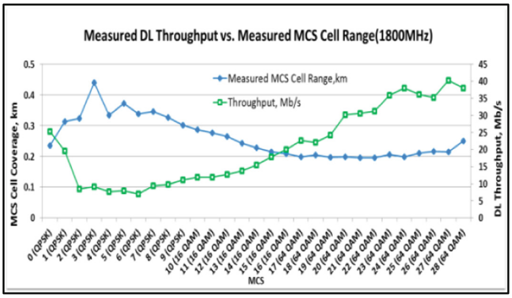
Figure 6 shows the cell capacity DL throughput against the MCS cell range. The horizontal axis represents the MCS level, the blue line represents the corresponding principle coordinates for the MCS cell range (unit: km), and the green line represents the corresponding sub coordinates for the DL throughput (unit: Mb/s).

Table 1. Summary table of measured KPI signal analysis for each band in the urban areas of Banqiao District

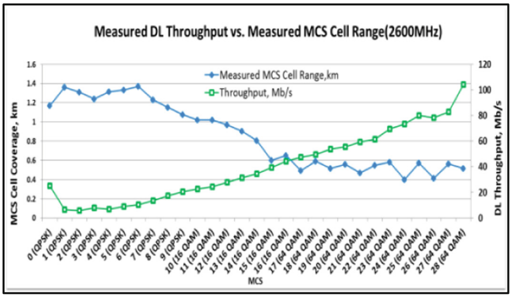
Band	700 MHz	1800 MHz	2600 MHz	Total
EnodeB	46	35	6	60
Cell range (Km)	0.31	0.26	0.96	0.45
SINR (dB)	5.04	6.19	5.71	6.04
DL throughput (Mb/s)	11.34	17.37	28.3	18.87
RSRP (dBm)	−87.22	−87.19	−115.7	−94.09



(a) LTE 700MHz



(b) LTE 1800MHz



(c) LTE 2600MHz

Fig. 6. Overall measurement of DL throughput for MCS (0)–MCS (28) vs. MCS cell range for MCS (0)–MCS (28) corresponding to the MCS levels for each band in Banqiao District. (a) LTE 700 MHz, (b) LTE 1800 MHz, and (c) LTE 2600 MHz (Color figure online).

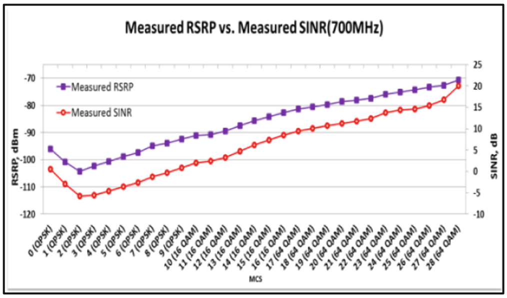
(a) The corresponding average DL throughput for each MCS from MCS (0) to MCS (28) under the 700-MHz band were in the range of 11.32–40.18 Mb/s, with an overall MCS average DL throughput of 11.34 Mb/s. The changes in the corresponding distances for each MCS and the DL throughput had a correlation of −0.854, displaying a significant negative correlation.
(b) The corresponding average DL throughputs for each MCS from MCS (0) to MCS (38) under the 1800-MHz band were in the range of 25.38–38.09 Mb/s, and the overall MCS average DL throughput was 173.37 Mb/s. The correlation between the changes in the corresponding distances for each MCS and the DL throughput was −0.747, indicating a significant negative correlation.
(c) The corresponding average DL throughputs for each MCS from MCS (0) to MCS (38) under the 2600-MHz band were in the range of 24.94–104.28 Mb/s, and the overall MCS average DL throughput was 28.30 Mb/s. The changes in the corresponding distances for each MCS and the DL throughput had a correlation of −0.9, demonstrating a significant negative correlation.

The average DL throughputs for the 700-, 1800-, and 2600-MHz bands in this measurement data analysis were approximately 11.34, 17.37, and 28.30 Mb/s respectively. According to the data, although LTE uses the orthogonal frequency-division multiple access technology, the 700-, 1800-, and 2600-MHz bands possess distinct IBs, which strongly influence DL throughput, with the wider bandwidth yielding a higher throughput. The bandwidths for both 700- and 1800-MHz bands measured in this study were 10 MHz, whereas the 2600-MHz band had a bandwidth of 20 MHz. Because a wider bandwidth results in a higher throughput, as shown in the data, the DL throughput of the 2600-MHz band was up to 28.30 Mb/s, which was greater than those of the 700- (11.34 Mb/s) and 1800-MHz (17.37 Mb/s) bands.

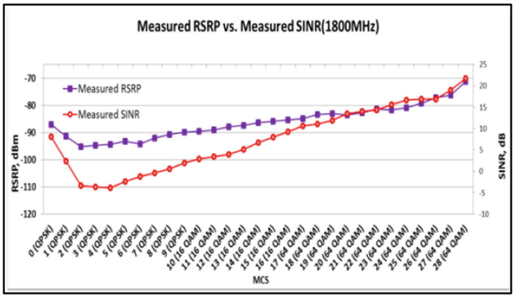
These data also indicated a negative correlation between DL throughput and distance, with SINR as the major influencing factor for DL throughput; thus, a shorter distance to the BS yielded a higher SINR. The UE obtained a higher MCS level, leading to a higher transmission rate, which increased the number of bits per second transferred, thereby enhancing the transmission of DL throughput in the same transmission bandwidth. Conversely, a greater distance away from the BS yielded a lower DL throughput.

Figure 7 presents the measured RSRP against the measured SINR. The horizontal axis represents the MCS level, the purple line represents the corresponding coordinates of the RSRP (unit: dBm), and the red line represents the corresponding sub coordinates for the SINR (unit: dB).

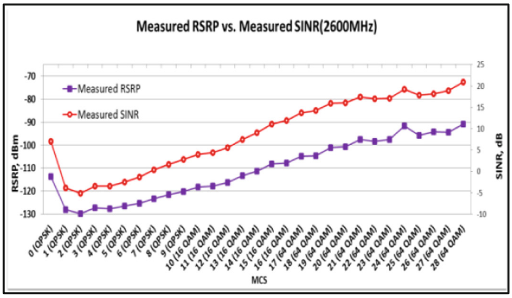
(a) The RSRP means for each MCS from MCS (0) to MCS (28) under the 700-MHz band were between −113.68 and −90.86 dBm, and the overall MCS RSRP mean was approximately −87.22 dBm. The correlation between the changes in the corresponding distance for each MCS and the RSRP was 0.994.
(b) The corresponding RSRP means for each MCS from MCS (0) to MCS (28) under the 1800-MHz band were between −87.13 and −71.3 dBm, and the overall MCS RSRP mean was 87.19 dBm. The correlation between the changes in the corresponding distance for each MCS and the RSRP was 0.979.



(a) LTE 700MHz



(b) LTE 1800MHz



(c) LTE 2600MHz

Fig. 7. RSRP for MCS(0)–MCS(28) vs. SINR corresponding to the MCS levels of each band measured in Banqiao District. (a) LTE 700 MHz, (b) LTE 1800 MHz, and (c) LTE 2600 MHz (Color figure online).

(c) The RSRP means for each MCS from MCS (0) to MCS (28) under the 2600-MHz band were between −115 and −90.86 dBm, and the overall MCS RSRP mean was approximately −115.70 dBm. The correlation between the changes in the corresponding distance for each MCS and RSRP was 0.994.

The resulting means for the 700-, 1800-, and 2600-MHz bands obtained from the average RSRP in this analysis were −87.22, −87.19, and −115.70 dBm, respectively.

The data indicated that an increase in the RSRP yielded a stronger SINR for the 700- and 2600-MHz bands, whereas the proportional relationship between the RSRP and SINR under the 1800-MHz band was less satisfactory when the strength of the former increased, signifying a lower interference in the 700- and 2600-MHz bands compared to the 1800-MHz band. The measurement data were roughly consistent with the original estimation before the study was conducted; thus, a lower frequency yields a more satisfactory RSRP performance, whereas a higher frequency results in a more rapid attenuation, causing an inferior RSRP performance.

4 Discussion

The results for Banqiao District in New Taipei City indicated that of the 60 linked BSs that were measured, 46 supported the 700-MHz band, 35 supported the 1800-MHz band, and 6 supported the 2600-MHz band. In total, more than 110 000 samples were obtained. The cell range means for each MCS from MCS (0) to MCS (28) were in the range of 0.91–0.19 km, and the overall average MCS was 0.93 km. The average DL throughputs for each MCS from MCS (0) to MCS (28) were in the range of 22.91–49.71 Mb/s, with an overall MCS average throughput of 18.87 Mb/s. The corresponding SINR means for each MCS from MCS (0) to MCS (28) were between −5.33 and 20.38 dB, and the overall MCS SINR mean was approximately 6.04 dB. The corresponding RSRP means for each MCS from MCS (0) to MCS (28) were between −106.9 and −73.83 dBm, with an overall MCS RSRP of approximately −94.09 dBm.

Figure 8 compares the measured SINR with that required for 3GPP. The figure reveals a positive correlation between the measured curve and the 3GPP curve. According to the figure, the SINR demand increased following a rise in the MCS level, and the measured DL throughput and required 3GPP DL throughput displayed a correlation of up to 0.930.

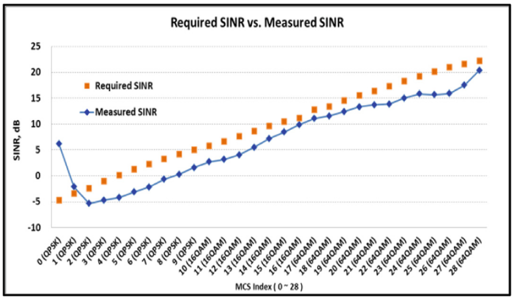


Fig. 8. Comparison of the theoretically required SINR for MCS (0)–MCS (28) and the measured SINR in Banqiao District.

The cell capacity DL throughput was also compared with the 3GPP with MIMO 2 × 2 DL throughput in Fig. 9.

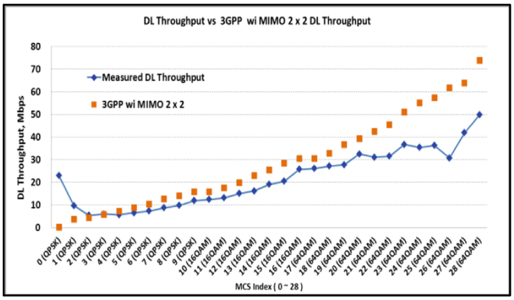


Fig. 9. Comparison of the overall measured theoretical DL throughput for each MCS level from MCS (0)–MCS (28) and the measured DL throughput in Banqiao District.

The measured curve on Fig. 9 was consistent with the 3GPP DL throughput curve; the theoretical and the measured DL throughputs demonstrated a correlation of up to 0.93. The data indicated that the superior modulation technology (QPSK/16QAM/64QAM) increased the number of bits transmitted per second, thereby enhancing the DL throughput under the same bandwidth.

Table 1 lists the measurement data for Banqiao District. As mentioned in Sect. 3.2, electromagnetic theory states that a lower frequency in the 700-MHz band leads to a smaller attenuation, which should result in a greater coverage distance.

However, the measurement data illustrated that the coverage distances for the 700-, 1800-, and 2600-MHz bands were inconsistent with the theoretical estimation. The average distances for the 700-, 1800-, and 2600-MHz bands were 0.31, 0.26, and 0.96 km, respectively. The 700- and 1800-MHz bands shared the characteristics of a shorter coverage distance following a rise in frequency. However, the characteristics displayed by the 2600-MHz band were inconsistent with the description according to electromagnetic theory, whereby a higher frequency leads to a greater attenuation and a shorter coverage distance.

Although the measurement in this study locked on separately to the 700-, 1800-, and 2600-MHz bands, the study did not lock on to a specific BS. Because the bases stations supporting the 700- and 1800-MHz bands were more densely deployed than those supporting the 2600-MHz band, mobile phones determine the current signal strength when the UE is farther away from the BSs during the mobile test. Because the BSs supporting the 2600-MHz band were deployed farther apart, the mobile phones were unable to locate neighboring BSs that with a satisfactory signal to support the 2600-MHz band even when their signal strengths were extremely weak, thus causing the data to indicate that the 2600-MHz band possessed a greater coverage distance.

Table 2 shows that the correlation analysis of the measured KPI signals for each band in the urban areas of Banqiao District. The measurement data showed a significant negative correlation between the MCS cell range and the RSRP, SINR, and DL throughput of each band, indicating that a shorter distance to the BSs yielded a more satisfactory RSRP, and a higher SINR was obtained. The rise in SINR led to a higher MCS level used by the UE and a superior transmission rate, thereby achieving a higher throughput. The comparison between the measured KPI and the required 3GPP

Table 2. Correlation analysis of measured KPI signals for each band in the urban areas of Banqiao District

Band	700 MHz	1800 MHz	2600 MHz	All band
Measured SINR vs. MCS cell range	−0.981	−0.840	−0.967	−0.886
Measured DL throughput vs. MCS cell range	−0.854	−0.747	−0.900	−0.814
Measured RSRP vs. measured SINR	0.994	0.979	0.994	0.962
Required SINR vs. measured SINR	0.968	0.911	0.941	0.936
Required DL throughput vs. measured DL throughput	0.943	0.889	0.982	0.930

indicated that they had a correlation higher than 0.9. The measured cell range and required DL throughput exhibited a correlation of 0.889. The measured numerical curves in this study are thus consistent with the required 3GPP.

5 Conclusion

The measurement data showed that the SINR and DL throughput of the 700-, 1800-, and 2600-MHz bands were negatively correlated to the MCS cell range, whereas SINR and RSRP had a significantly positive correlation. The data also indicated that a shorter distance to the BS enhanced the SINR, thus obtaining a superior modulation method that improved the transmission rate and enhanced the DL throughput. A higher band under the same transmission bandwidth also possessed a higher throughput. The data illustrated an enhancement in SINR following an increase in the RSRP of the 700- and 2600-MHz bands, whereas the positive correlation between RSRP and SINR under the 1800-MHz band was less satisfactory following an enhancement in the former. This result revealed a lower interference in the 700- and 2600-MHz bands compared with the 1800-MHz band.

Finally, the measurement data were compared with the 3GPP theory; a high correlation was observed between them. The cell range calculation in this study will be an important step for coverage probability estimation of the on-site EnodeB in the future.

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