Performance Measurement of the LTE signal strength along Osaka – Yokohama railway using Tokaido Shinkansen high speed train

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Abstract **– The use of high-speed train has progressively increased over the past years and it has become the most important public transportation. With the rapid development of mobile communication, mobile telephone users are expecting higher network capacity and good connection quality. In that case, passengers are demanding a high quality of voice and data-rich communication. The main objective of this research is to study the performance of LTE in a high-speed railway from Yokohama to Osaka using a commercial measurement tool namely Nemo handy. The data collected from the measurement has been analysed using a software named Nemo Analyzer. The measurement analysis of the currently deployed LTE network is being done at the velocity of up to 300km/h. The measurements works were conducted in the morning, evening and night on six fine days. The results yields some useful information which is the SNR and RSRP are proportional to each other and the signal strength is proportional to the speeds. At last, this studies inferred that the speed of the train may affect the quality of the signal strength.**

I. INTRODUCTION

The rapid development of high-speed rail (HSR) in the world today making, it feasible to reach a maximum speed of almost 575 km/hour [1]. The communication signalling system is broadly the main part which is contributing to the safe operation of high-speed rail. Currently, in Malaysia GSM-R technology is still extensively being implemented while LTE technology still in developing phase despite the fact that this technology has been growing rapidly around the world. GSM-R, Global System for Mobile Communications Railway is an international wireless communications standard for railway communication and applications. GSM-R is part of the European Rail Traffic Management System (ERTMS) standard and carries the signalling information directly to the train driver, enabling higher train speeds and traffic density with a high level of safety. However, GSM-R cannot support demands for high data rate communication since it only provides a maximum data rate of 200 kbps, which is of satisfactory level for voice communication and railway control [2].

With the rapid growth of railway services, broadband communication systems for railway transportation called the Long Term Evolution for Railway (LTE-R) have been deployed. LTE technology is the fastest developing system in the history of mobile communication and the networks are capable of providing speeds of over 100 Mbps and scalable carrier bandwidths ranging from 1.4 MHz to 20 MHz [3].

Long term evolution (LTE) is commonly believed to be the promising system for future railway because of its high rate of data signalling and high bandwidth. The passengers on board used the data services to surf online applications, reading online books, playing online games and much more.

Study in [4] focused on plausibility of achieving MIMO functionality on a Swedish high speed train and has been conducted using LTE TSMW scanner, provided by Rohde & Schwarz. The purpose of the measurement is to analyse the LTE MIMO downlink traffic performance on a moving train. The train was typically moving between 100 to 200 km/h with an average speed of 180 km/h. The parameters collected including Reference Signal Received Power (RSRP), Signal to Interference and Noise Ratio (SINR), Base Station distance, Rank Indication (RI) and H Matrix and Condition Number (CN). The Radio Frequency data collected were all measured within the channel bandwidth of 5 MHz. This measurements indicated that a Condition Number of less than 15 dB can support MIMO and is achieved with the inter element distance of around 10 m. Thus, it makes MIMO actually plausible to implement for train communications.

According to [5], the authors have conducted a simulation using Network Simulator (NS2). The purpose of the simulation is to investigate the Internet traffic performance in high speed trains, considering various wireless channels to connect the high speed train and wireless access network. From the simulation results it can be concluded that the link delay (packet) has a significant impact on the traffic performance of Constant Bit Rate (CBR), FTP, http and email traffic.

The performance study of the internet traffic on high speed railways had been done in [6]. Mobile users require seamless connection especially when they are travelling. Further analysis is required when it comes to high mobility condition such as in railway to ensure quality user experience (QoE). In this paper, the traffic information related to the behaviour of Internet services over the commercial mobile network are collected. The measurements were conducted between Madrid-Malaga along 155 km for two major operators in Spain. This study used the TestDroil tool, developed by the University of Malaga, Spain to capture the IP traffic with the support of Android smartphone. After analysing the collected information, they are able to derive the quality metrics. They used several mobile devices and providers during the testing to obtain good results.

The paper in [7] investigates the performance of LTE with varying velocities under operational condition (MIMO Measurement Configuration). The measurements were conducted in Western Europe using intercity train with velocities between 100 to 200 km/h using a commercial drive-test software (Nemo Outdoor version 7:3:0:6). Results indicated that the performance of LTE remains robust up to 200 km/h and that the SNR is the most important factor to ensure reliable operation.

To the best of author's knowledge, there is no study that has been done to investigate on the performance of LTE while travelling in the high speed railway in Japan. Thus, this research investigates the performance of LTE along the Osaka to Yokohama line. The Tokaido Shinkansen is a train operating on the Shinkansen railway system line that connects Japan's three largest metropolitan areas, (Osaka, Nagoya and Yokohama). There are three types of train operating on the Tokaido Railway, which is the fastest to the slowest, (Nozomi – 320 km/h, Hikari – 297 km/h and Kodama – 285 km/h). These measurements have been conducted along 8 railway stations, for 2 hours and 40 minutes at three different occasions, morning, evening and night. It has been observed that the journey encompassed obstructions such as underground tunnels, hilly terrains, urban and suburban environments.

The rest of this paper is structured as follows. The data collection activity during the drive test of the LTE network is described in section II. Section III elaborates on the analysis of the measurement results which discussed on the scenario of the LTE signal on board of a train. Finally, conclusive remarks are given in section IV.

II. MEASUREMENT SETUP AND METHODOLOGY

A. On-board monitoring set up

The measurement works have been scheduled along the 484 km railway line, between the cities of Yokohama and Osaka. The data have been collected while the train is in the moving and idle conditions. All measurements were recorded using Band 3 with Frequency division duplexing mode (FDD), operating frequency of 1800 MHz and having a 20 MHz bandwidth. The parameters of handover, SNR, RSRP, RSSI, train's speed, throughput, latitude and logitude will be stored in the memory for analysis. Figure 1 shows the Nemo handy tool in mobile phone.

Figure 1: Nemo handy in mobile phone

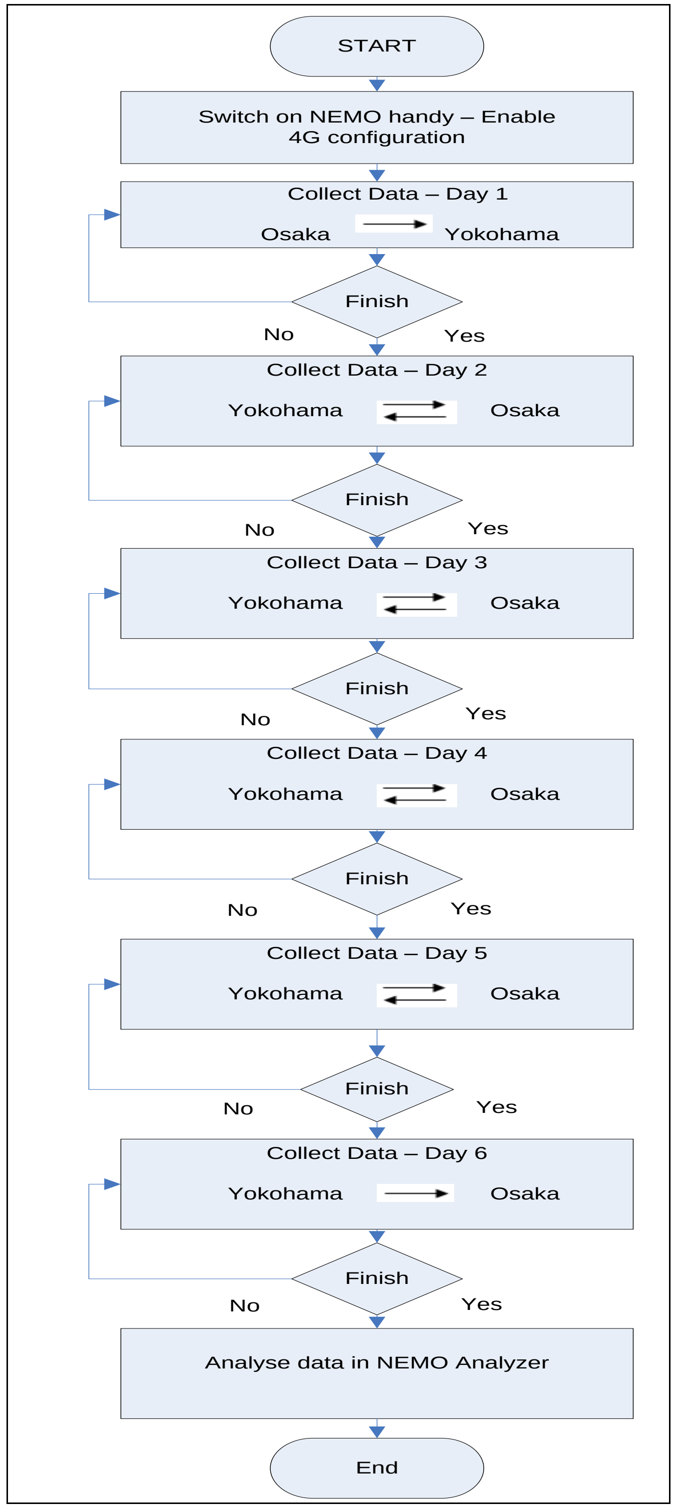

Figure 2: Flowchart of the LTE measurement

Nemo Handy-A is a portable device, an engineering tool use for measuring and monitoring the air interface of digital networks. This device supported the following networks:

- GSM
- WCDMA
- HSPA
- LTE
- CDMA

Nemo Handy-A is an effective equipment use for tracing digital networks and to collect the measurement results. The data collected will be stored into the memory card.The measurement results will provide useful information for network optimization, verification, and maintenance purposes. The results can be easily viewed by using the Nemo analysis tool named Nemo Analyzer for Windows [8]. Prior to starting the measurements, the Nemo Handy must be installed in a mobile phone. Log file which is the data collected from test drive activity is then saved into the memory card and will be converted to nmf format using Nemo Analyzer software. Nemo Analyzer is used to analyse the data collected and it is a laptop-based software test drive tool which supports over 200 terminals and capable of scanning receivers from various vendors of all major network technologies. The software is protected with a license key. Figure 2 depicts the methodology of the measurements.

The speed of the trains are between 200 to 290 km/hour and the measurements for each parameter were collected at three different occasions for 6 days and the details on the parameters being measured are as specified in Table 1.

Table 1: The parameters in the drive test activity

Parameter	Description
RSRP	Expressed in dBm, measure cell site received signal strength
RSRQ	Expressed in dB, measure cell site received signal quality
SNR	Expressed in dBm, measure the power level

The performance of LTE network coverage was affected by various factors such as:

a) Train Speed – The higher the train speed, the higher the frequency of handover between base station. At low speed, the channel conditions are largely static, influenced by slow fading and vice versa. The faster the speed, the greater the shift and, therefore, the greater is the interference. Passengers pass through multiple cells in a very short time. This will cause signalling storm, leading to drop call.
b) When a train is running at 300-500 km/h, handover occurs every 7 seconds or less. Such frequent handover during extra-high speed movements lead to a large amount of signalling or even to a signalling storm. Moreover, the train is running between cell centers and cell edges, which significantly impact the service rate and even causing service drop [2].
c) Weather - Weather conditions can have a huge impact on the wireless signal integrity. For example, fog can weaken the signals as they pass through.
d) Environment – Geographical condition can have a significant impact on the signal strength such as terrains (hills and plains), building, tunnel and human density. The more obstructions between the transmitter and receiver, the more probability there is that the signal strength will be affected and cripple signal transmissions.

III ANALYSIS OF RESULTS AND DISCUSSION

This paper provides an experimental study on LTE measurement along Tokaido railway line (Osaka – Yokohama) as shown in Figure 3 covering a distance of 484 km. The train named HIKARI is used for this measurement with speeds up to 300 km/h. The measurement results have been recorded using a device call NEMO handy. NEMO handy is a network measurement device used to collect the data and the results is generated using Nemo Analyzer software [3]. It has been used to measure and analyzed the parameters such as RSRP, RSSI, RSRQ and SNR. On the first day, measurements were taken on route from Osaka to Yokohama and on the following days measurements were taken on route from Yokohama to Osaka and back to Yokohama. The train stop at 8 stations along the way as follows; Osaka, Kyoto, Maibara, Gifu Hashima, Nagoya, Toyohashi, Shizuoka and Yokohama and the duration of the journey is approximately 2 hours and 40 minutes. In this study, the measurement has been done to the network operator of NTT Docomo Japan. The main objective of the study is to measure the received signal strength along the Tokaido line at three different times which are morning, evening and night respectively. The following are details of the measurement carried out:

- Morning (8:25am – 11:05am)
- Evening (5:15pm – 7:50pm)
- Night (8:30pm – 11:10pm)

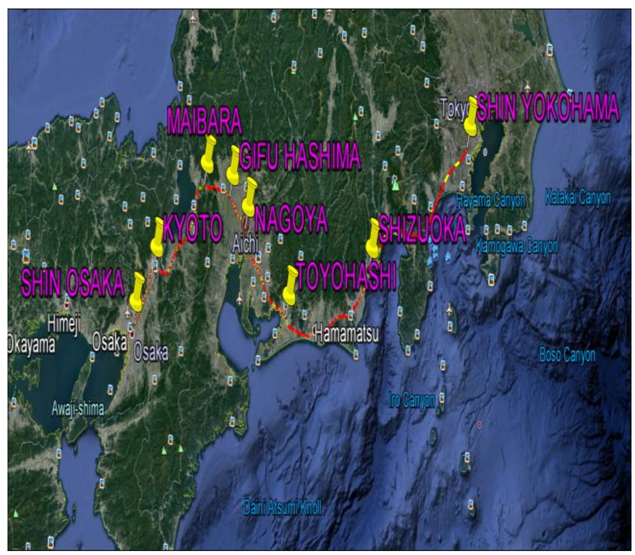

Figure 3: Measurement area of the drive test – Google earth

Received signal strength in the morning

By using NEMO handy, it is shown that the coverage of Tokaido Shinkansen line between cities of Osaka and Yokohama were fully covered by the LTE network. The drive test activity as shown in figure 4. The graph shows that the best signal quality was captured when the train is not moving or idle. It was observed that the highest RSRP value is -89.5 dBm which is located at the Nagoya station at 10:09. The coverage of this area is excellent and being influenced by the geographical condition of earth (flatness), population density (medium density) and the speed of the train. It is observed that, when the train is at the highest velocity of 286 km/h, the value of RSRP dropped significantly which is, -130.5 dBm and it was spotted at Odawara area, (Kanagawa prefecture) at 8:39. The train's speed and the long tunnel that the train has to pass through has affected the quality of the signal.

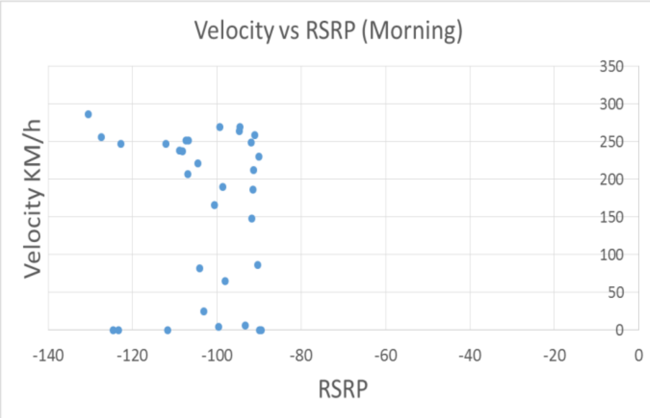

Figure 4: Scatter plot of RSRP versus Velocity (Morning)

The RSRP value which is greater than -80dBm represent excellent Quality of Service (QoS) with optimal coverage. The values between -90 and -80dBm are considered as of good qualities. If the RSRP is less than -90dBm, the coverage is identified as bad quality [10].

The SNR parameter is used to observe the relationship between the SNR and RSRP. Higher value of SNR means that the signal strength is stronger in relation to the noise levels, which allows higher data rates and fewer retransmissions. The effect of SNR versus RSRP is depicted in Figure 5. It can be noticed that higher SNR values occur when the value of RSRP is higher than -100 dBm. The highest value of the SNR is 17.6 dB while the RSRP value is at -89.5 dBm and this value was captured at the Nagoya station at 10:09, when the train is idle. The SNR values show an increasing trend with the increasing of RSRP.

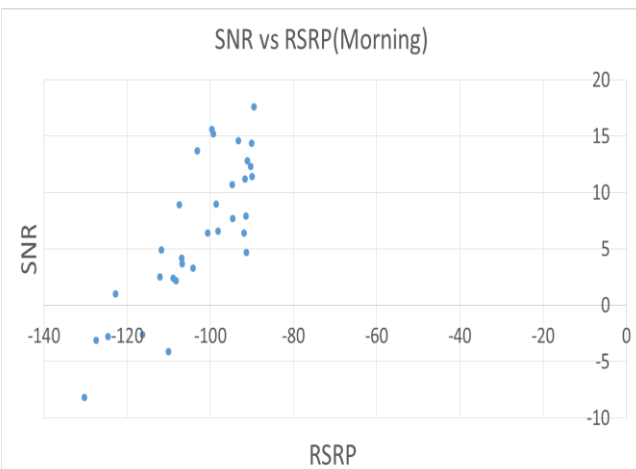

Figure 5: Scatter plot of SNR versus RSRP (Morning)

Received signal strength at evening

Measurement was again taken in the evening. Figure 6 illustrates a scatter graph that shows the received signal strength along the 2 hour and 40 minutes journey between Osaka and Yokohama. From the measurement, when the train is at the highest velocity of 297 km/h, the value of RSRP is -137.9 dBm and it was captured at Yokohama city at 19:32. From the observation, Yokohama can be categorized as an area with high population density and it is also a center of tourism. In addition, the measurement is done during the rush hour where people commute back from work and the train is at full capacity.

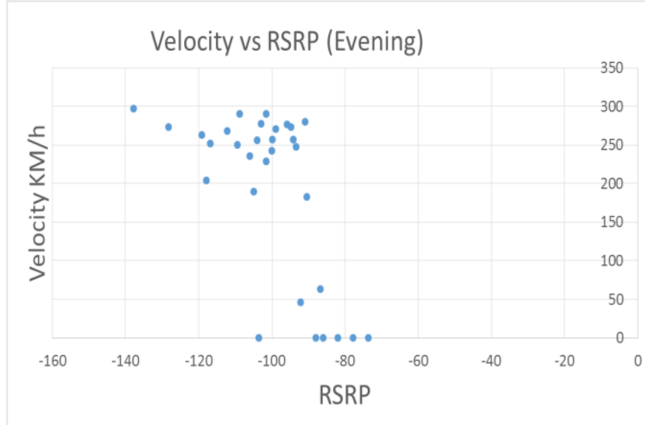

Figure 6: Scatter plot of Velocity versus RSRP (Evening)

Furthermore the train is moving at the highest speed, 297 km/h. Meanwhile the excellent coverage was observed at 17:57 and the RSRP reading is -73.6 dBm, which is detected at the Maibara station, that is when the train was idle.

SNR value for this time also has been measured and depicted in figure 7. From the measurements it shows that the highest value of SNR was when the train passed through the area of Maibara station which is 27.6 dBm while the RSRP was recorded as the highest reading, -73.6 dBm. As aforementioned, the highest value of SNR will lead to the highest value of RSRP [3]. It was expected that with the increase of SNR will also increase the throughput. The lowest value of SNR is -14.3 and was detected at city of Yokohama. The SNR values show a decreasing trend with the decreasing of RSRP.

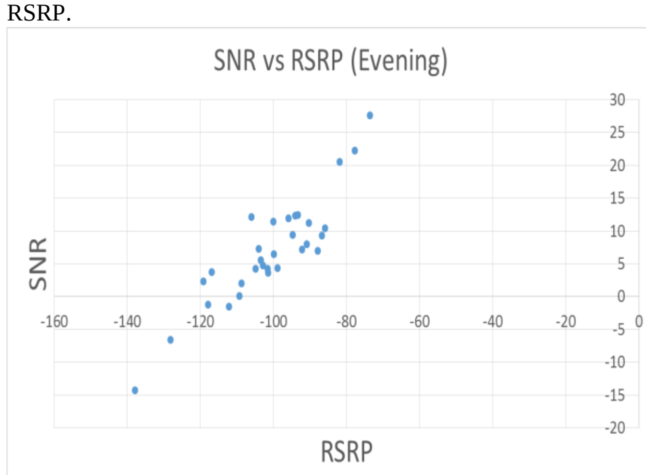

Figure 7: Scatter plot of SNR versus RSRP (Evening)

Received signal strength at night

In order to get an accurate reading on the signal strength, the test drive activity has been conducted at night. The signal strength versus velocity can be observed as having the same trend as in figure 4 and 6. This scenario shows that when the train is in a stationary position, the RSRP value is at the highest reading, -76.5 dBm while SNR reading is 22.9dB and was spotted at the Nagoya station. The lowest value of the RSRP is -140 dBm while the SNR values is at -14.8 dB when the train is at the second highest speed, 279km/h as illustrated in figure 8 and 9 respectively. It was spotted at Otsu area which is near to the shore of Lake Biwa and the mountainous area.

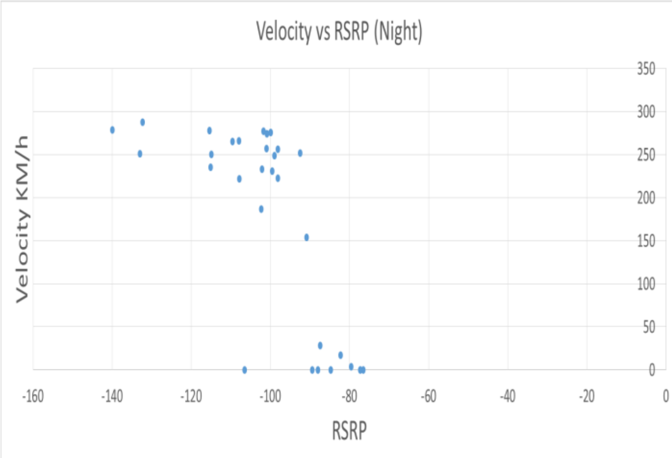

Figure 8: Scatter plot of Velocity versus RSRP (Night)

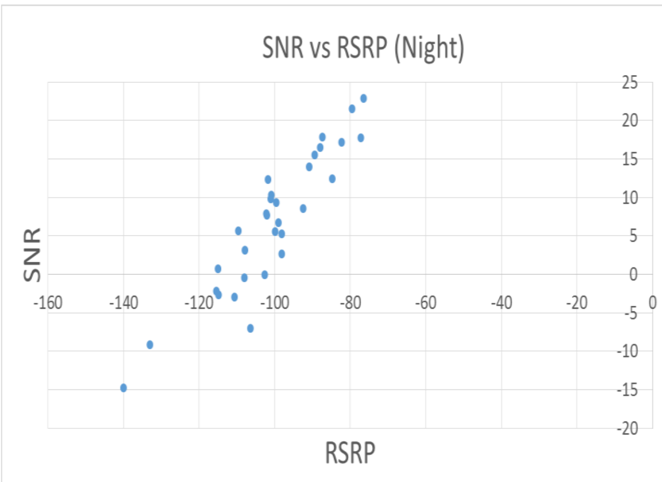

Figure 9: Scatter plot of SNR versus RSRP (Night)

Occasion	RSRP	SNR
Morning	-89.5	17.6
Evening	-73.6	27.6
Night	-76.5	22.9

Figure 10: Measurement data of RSRP and SNR

Figure 10 shows that the best signal strength that has been captured is in the evening due to the highest RSRP and SNR value, -73.6 dBm and 27.6 dB. It observed that when the RSRP value is increased, the SNR value will increase too.

IV. CONCLUSIONS

High speed trains are extensively being used nowadays and there are increasing needs for it's use by the public sector. With the increasing pace of life of the population, there are also increasing need to continuously increase the speed of the train to cater for the public need. This pose a very big challenge in the field of communications to provide a reliable and high quality mode of communication to fulfill users's demand to have the best access to the internet usage, regardless of locations and speeds. From the results obtained, increasing the train's speed will decrease the quality of the LTE signal strength. Nevertheless the network quality along the Japan Shinkansen high speed railway is still satisfactory to fulfill users's demands. As for future works, the results from these measurements will be a reference point to improve the LTE coverage in Malaysia especially in the field of high speed transportations. Due to limitation of work, further in depth research is required such as throughput and increase the frequencies of the measurement activities. These are very meaningful for future high speed transportation development in Malaysia.

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