Evaluation of WiFi Broadband Network on the Jabodetabek Commuter Line

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Abstract: This research evaluates the performance of WiFi networks based on the Universal Mobile Telecommunications System (UMTS) backbone on the Commuter Line (CL) to identify technical issues in providing stable internet services in public transportation with high mobility. The main gap lies in the inability of the existing infrastructure to maintain service continuity when the train is mobile compared to when it is immobile. This research uses an experimental method involving three testing scenarios (using a backbone modem, a signal measurement system, and a smartphone device); the study measures Quality of Service (QoS) parameters. Research results show that throughput passing through the UMTS backbone decreased by

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16.8% to the DNS server and 12.68% to detik.com when the commuter line was in motion. Furthermore, packet loss passing through the UMTS backbone increased by 13.6% to the DNS server and 11.2% to detik.com when the commuter line was moving. Then, the round-trip time passing through the UMTS backbone increased by 175.50% to the DNS server and 179.25% to detik.com when the commuter line was in motion. These results confirm that high mobility causes significant signal degradation, making current UMTS networks not yet capable of supporting users' broadband needs inside train carriages. The contribution of this research is is recommending a new infrastructure design in the form of optimizing BTS placement or using train repeaters to address interference. Therefore, the conclusion of this research is the need to strengthen transmission in the CL so that the WiFi implementation can achieve the expected reliability standards.

Keywords: Communication System, Commuter Line, High-mobility Railway, Train Repeater, UMTS.

Introduction

Based on observations of Wireless Fidelity (WiFi) services regarding cellular network backbone availability on mass transportation modes, namely the Commuter Line (CL), the main issue found in a moving train environment is signal quality fluctuation, which directly affects throughput, delay, and packet loss, thereby impacting the user experience of internet-based data services. Previous research shows that evaluating cellular network performance through live measurement can be conducted using radio parameters such as Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), Signal to Interference Noise Ratio (SINR), throughput, packet loss, and latency. According to (Zmyslowski & Kelner, 2022) , there is a strong correlation between radio parameters and QoS performance in drive test scenarios, while (Afroz et al., 2015) and (Shashidhar et al., 2022) emphasize that degradation of SINR and RSRP significantly affects throughput and handover processes, particularly in high mobility environments. Therefore, comprehensively, network selection and QoS availability are needed to support operations. Although Long Term Evolution-Advanced (LTE-A) technology has been widely studied, research on the Universal Mobile Telecommunications System (UMTS) as the WiFi backbone in CL is still relatively limited. In fact, UMTS is still used as an existing network and serves as the data service backbone in certain areas.

The research centers on suburban cellular networks, emphasizing primary QoS parameters and drive test methodologies, yet it neglects the context of railroad transportation.

Consequently, this study serves as a pertinent reference for field measurement techniques (Zmyslowski & Kelner, 2022). The study (Singh et al., 2023), examined railroad communication with a focus on latency and coexistence parameters; however, their study was emulator-based. Consequently, this research serves as a comparative analysis, illustrating the importance of real field measurements. This study (Wang et al., 2020), examine LTE-R, concentrating on security and access; their contribution primarily addresses security, while this research highlights QoS performance and network backbone, and the study (Putri & Silalahi, 2020), analyzed the MRT Bundaran HI–Senayan network utilizing the parameters RSRP, RSRQ, SINR, and throughput; however, they did not assess WiFi as an end-user service. This study, then, looks at the open commuter line (CL) environment and uses UMTS as the WiFi backbone. (Budiyanto et al., 2024), subsequently examined urban cellular networks, focusing on parameters such as throughput, SINR, and network capacity, while neglecting high mobility scenarios and mass transportation. Consequently, this research serves as a reference for cellular performance and network feasibility. (Silalahi, Amaada, et al., 2024), in their study on urban network planning, employed a link budget, MAPL, and cell coverage methodology; however, it was static and lacked real-time mobility validation. Consequently, this research utilizes the link budget concept as the evaluation foundation. (Beny et al., 2024; Silalahi, Qhumaeni, et al., 2024), examine enterprise networks, focusing on parameters such as throughput, latency, reliability, round-trip time (RTT), packet loss, and availability; however, they do not consider cellular radio access and mobility. This omission positions them as a comparative reference in the realm of backbone QoS and network resilience. (Simanjuntak et al., 2023), investigated MPLS networks considering parameters such as delay, packet loss, and convergence time, albeit through simulations; consequently, this study underscores the necessity of field measurements on cellular networks. Lastly, (Atik et al.) looked at railroad communication infrastructure, focusing on end-to-end latency and deployment of FRMCS in rural areas. However, they did not test end-user WiFi. This research is important because it can be used to evaluate the current network (UMTS) as the WiFi backbone in an urban commuter line setting.

Furthermore, the increasing demand for continuous internet access has driven the adoption of WiFi technology due to its ease of deployment and user-friendly connectivity. Previous studies indicate that WiFi can deliver high data rates and reliable user experiences, and it is commonly integrated with cellular networks as a backbone to expand service coverage. However, most existing works still emphasize stationary environments or scenarios with limited mobility, which may not adequately represent the operational conditions of mass transportation systems with high-speed movement and frequent signal fluctuations, such as commuter trains (Mazhar et al., 2023; Munasinghe & Jamalipour, 2010; Rahman et al., 2022)

Technically, WiFi has continuously evolved in terms of capacity and spectrum efficiency. Nevertheless, the end-user performance of WiFi services is strongly influenced by the quality and stability of the backbone network that provides internet connectivity. In this context, UMTS remains an existing cellular infrastructure deployed by operators and may serve as a potential backbone for broadband WiFi services. Despite its availability, the feasibility and performance of UMTS as a WiFi backbone under high-mobility environments, particularly in urban Commuter Line operations, has not been extensively evaluated through empirical field measurements.

The remainder of this article is structured as follows: Research Methods describes the system flowchart and broadband WiFi network architecture, network configuration design, and testing scenarios. Results and Discussion present measurements of throughput, packet loss, RTT, and signal strength, followed by an overall system analysis. Finally, the conclusion summarizes the main findings.

Research Method

Flowchart Design

Starting with designing the CL WiFi network topology, including the configuration of access points (AP), routers, and the UMTS backbone connection. After installation and configuration, an initial validation process is carried out to ensure the network system functions properly. If the results of the initial testing do not meet the connection success criteria, the network configuration is adjusted until the system is ready for measurement.

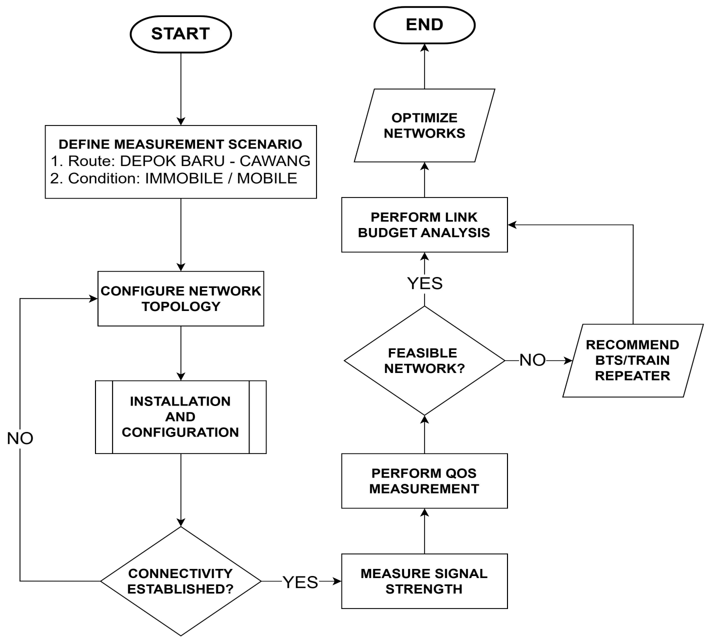


Figure 1 Flowchart system

This research uses an experimental method to evaluate the performance of a Broadband WiFi network using UMTS in a CL environment. The research process is designed through the flowchart in Figure 1, which illustrates the structured stages.

1. Measurement design and scenario

   Measurements were carried out along the Depok Baru–Cawang route. Testing was conducted under 2 conditions, namely:

   a. Immobile condition, when the train is stationary at the station, and

   b. Mobile condition, when the train is moving at normal operational speed.

   Each measurement scenario was repeated 5 times, and in each repetition, 50 ping test packets were sent. Each measurement session was conducted for the same duration and used identical network parameters.
2. QoS parameters

   The QoS research parameters were chosen based on their relevance to WiFi-based data services in high-mobility environments, as well as their compliance with IP network evaluation standards. The parameters analyzed include throughput, packet loss, and RTT.

   The selection of these parameters is based on previous literature, which identifies the main indicators of network performance and is influenced by user mobility as well as access radio network quality.
3. Data collection procedure

   Based on Figure 1, data collection was carried out using two approaches, namely:

   a. Signal quality-based data collection, to evaluate the signal strength of the mobile station received from the UMTS network under both mobile and immobile conditions.

   b. Ping test-based data collection, to obtain throughput, packet loss, and RTT values at several test nodes, including WiFi routers, internet gateways, DNS servers, and external servers.

   Measurements were conducted sequentially according to the evaluation flow, starting from testing local connectivity to the connection with external servers, in order to isolate the sources of network performance degradation.
4. Data processing and analysis method

   Measurement data was collected from each QoS parameter in every test scenario. Comparisons were made between mobile and immobile conditions to identify the impact of mobility on network performance. The analysis was conducted by comparing the measurement results against the Telecommunications and Internet Protocol

Harmonization Over Networks (TIPHON) standards. Then, link budget calculations were performed to assess network feasibility.

5. Decision and iterative analysis

   In this section, if the measurement results indicate a significant performance degradation, a deeper analysis is conducted to identify the main causes, whether from signal quality, infrastructure design, or network distribution mechanisms. The results of this analysis are then used as a basis for formulating recommendations for network infrastructure design.

WiFi broadband network architecture

The network architecture consists of user devices (e.g., HP1, HP2, and HP3) connected to a WiFi network through a wireless interface. The devices and WiFi router are on the 192.168.1.0/24 subnet, where the address 192.168.1.1 serves as the WiFi router interface (Node A), which is the first measurement point in the ping test scheme. This subnet represents the WiFi access network inside the train.

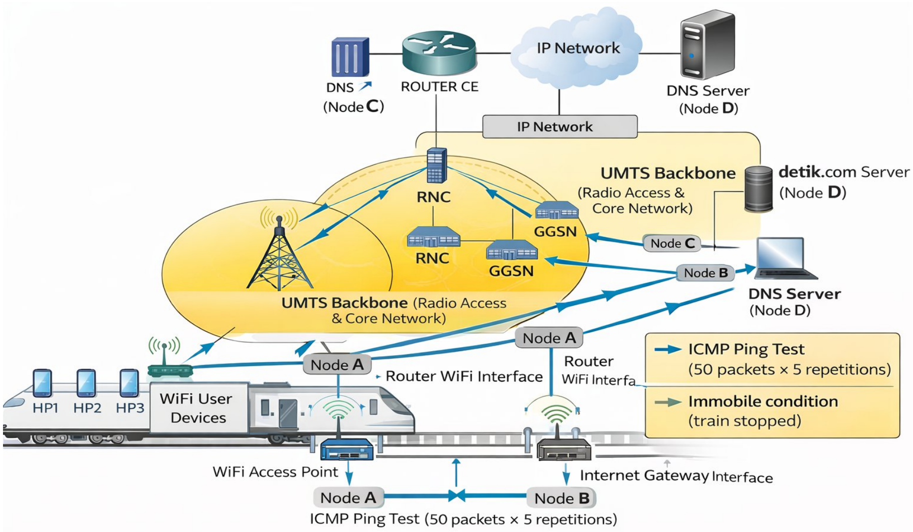


Figure 2 WiFi broadband network architecture

Figure 2 shows the network architecture used in this research. The WiFi router is then connected to the internet gateway device through the WAN interface with the address 192.168.137.101, while the internet gateway uses the address 192.168.137.1 on the LAN side. This 192.168.137.0/24 subnet segmentation is used to separate the WiFi network from the UMTS backbone network, allowing for the identification of performance degradation originating from the gateway or network backbone. This internet gateway interface is designated as Node B in the testing. On the external network side, the DNS servers with addresses 192.168.4.28 and 192.168.39.28 are designated as Node C, while the detik.com server with address 203.190.242.69 is designated as Node D. Ping testing was conducted gradually from the WiFi user's device to Node A, Node B, Node C, and Node D, and the IP address allocation is shown in Table 1.

Table 1 IP address allocations

Devices	Interface	IP Address
Notebook	Wireless Interface	192.168.1.101/24
Router Wireless	Wireless Interface	192.168.1.1/24
	WAN Interface	192.168.137.101
Internet Gateway	LAN Interface	192.168.137.1
	USIM Interface	DHCP
DNS Server	LAN Interface	192.168.4.28//192.168.39.28
Server: detik.com	LAN Interface	203.190.242.69
HP1	Wireless Interface	192.168.43.59
HP2	Wireless Interface	192.168.43.1
HP3	Wireless Interface	192.168.43.60

Based on Table 1, the IP addressing scheme is configured to distinguish the WiFi access network (192.168.1.0/24) from the UMTS backbone segment (192.168.137.0/24). The WiFi router acts as the access point for end-user devices, while the internet gateway provides connectivity to the UMTS network and external internet services. This allocation ensures that each node in the testing scenario (Node A to Node D) can be clearly identified and evaluated during latency and packet loss measurements.

UMTS Network Design Configuration

UMTS design needs to be supported by link budget analysis to assess whether the quality of the received signal is still within the feasible service coverage limits. Therefore, the link budget analysis uses the MAPL, which is then compared with the results of signal strength measurements and QoS results under both moving and stationary train conditions (Budiyanto & Al Hakim, 2020; Budiyanto & Gunawan, 2023; Budiyanto et al., 2021; Silalahi et al., 2021)

Table 2 Link budget information

Description	Information
Frequency	1860-1870 MHz
UMTS channel bandwidth	3.84 MHz
Antenna height	30 m
Mobile station height	1.5 m
Fast Fading	10 dB
Commuter line speed	80 km/h
Transmit power	24 dBm
Gain antenna	2 dB
Cable loss	0 dB
Noise figure BTS receiver	5 dB
Interference margin	3 dB
Soft handover gain	2 dB
In-car loss	8 dB
Log normal fading margin	4.2 dB

From Table 2 above, it is the link budget calculation refers to the parameters used and explained based on the steps described below.

Step 1 — Calculate EIRP (Effective Isotropic Radiated Power)

One of the factors that affects MAPL is Effective Isotropic Radiated Power (EIRP) or Equivalent Isotropic Radiated Power (EIRP), which is the power value emitted by a directional (sectoral) antenna to produce the peak power observed in the direction of the antenna's maximum gain radiation. The EIRP formula is shown in equation 1.

$$EIRP = Transmit\ power\ (dBm) + Antenna\ Gain\ (dB) - Cable\ Loss\ (dB)$$

$$= 24 + 2 - 0 = 26\ dBm \quad (1)$$

Langkah 2 — Calculate the Thermal Noise Power in UMTS bandwidth (3.84 MHz)

$$P_{dBm} = 10 \log_{10}(k_B T \times 1000) + 10 \log_{10}(\Delta f) \quad (2)$$

Next, Thermal Noise Density (TND) as the noise power per hertz at the receiver input, which is shown in equation 2.

Where P_{dBm} is the noise power of thermal noise, k_B is the Boltzman constant (1.38x10^{-23}J/K), T is the temperature and $\Delta f = 3.84MHz$ is bandwidth. Which is more commonly seen approximated for room temperature (T=300K) as seen Eq. 3 below.

$$P_{dBm} = -174 + 10 \log_{10}(3.84 \times 10^6) = -108.16\ dBm \quad (3)$$

Step 3 — Noise Figure dan Interference Margin

Next, the Noise Figure is the noise caused by the input from the BTS receiver. The Noise Figure usually has a value between 3-5 dB.

Step 4 — Fading Margin

The fourth factor that affects MAPL is the Fading Margin. Fading margin is the power reduction caused by the movement of the Mobile Station (MS). According to Chengshan Xiao (2023), the fast-fading margin for a maximum speed of 100 km/h is 10 dB.

Result and Discussion

Throughput

Table 3 shows the results of throughput measurements. There is a consistent performance difference between the moving (mobile) and stationary (immobile) train conditions across all test nodes. Quantitatively, the average throughput at Node D (detik.com server) decreased from 67.11% in the immobile condition to 58.62% in the mobile condition, representing a reduction of about 12.6% when the train is moving.

Table 3 Throughput measurement results

Info	Node A		Node B		Node C		Node D	
	Mobile	Immobile	Mobile	Immobile	Mobile	Immobile	Mobile	Immobile
1	74.803	74.348	75.379	74.563	71.874	74.37	67.64	69.195
2	72.713	75.057	75.432	74.953	49.514	71.246	39.191	74.549
3	71.388	74.966	60.381	73.882	58.869	74.921	67.704	59.57
4	75.02	74.256	75.244	75.262	50.906	73.278	63.91	56.86
5	73.583	74.652	51.549	73.882	71.547	70.062	54.652	75.386
Average	**73.5014**	**74.6558**	**67.549**	**74.5084**	**60.542**	**72.7754**	**58.6194**	**67.112**

Then, similar pattern is also observed at Node C, although with a slightly smaller decrease. In contrast, at Node A and Node B, the difference in throughput between mobile and immobile conditions is relatively small, indicating that the throughput degradation does not primarily originate from the onboard WiFi network or local connections within the train.

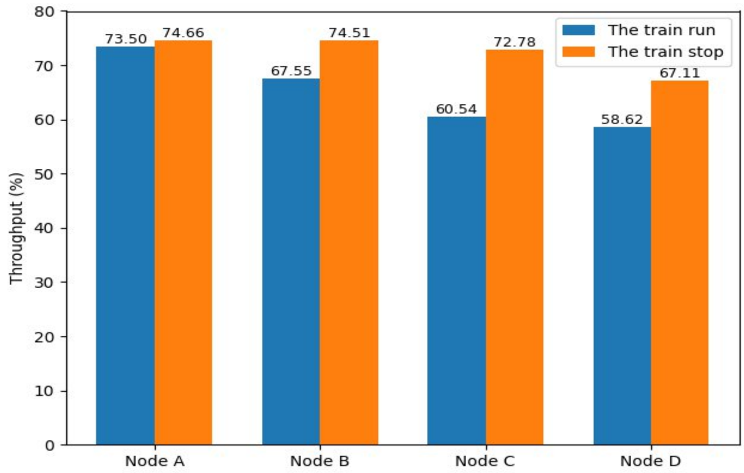


Figure 3 Throughput measurement results

The trend visualized in Figure 3 confirms that the throughput degradation in CL WiFi services is mainly influenced by the limitations of the UMTS backbone in maintaining performance in high mobility environments, rather than by WiFi network limitations. In immobile conditions, the more stable radio signal quality allows the mechanisms for radio resource scheduling and packet delivery to function more optimally, resulting in higher throughput achieved at Node C and Node D.

Packet Loss

Table 4 shows the results of the packet loss measurements. There is a contrast between the conditions of the train being stationary (immobile) and the train in motion (mobile). Under immobile conditions, all test nodes (Node A to Node D) showed no packet loss, indicating that the WiFi network, internet gateway, and UMTS backbone were able to maintain reliable packet transmission when the radio conditions were relatively stable. In contrast, under mobile conditions, packet loss began to appear significantly at Node C and Node D, with average values of 11.2% and 13.6%, respectively, while Node A and Node B still showed 0% packet loss.

Table 4 Packet loss measurement results

Info	Node A		Node B		Node C		Node D	
	Mobile	Immobile	Mobile	Immobile	Mobile	Immobile	Mobile	Immobile
1	0	0	0	0	12	0	8	0
2	0	0	0	0	26	0	10	0
3	0	0	0	0	14	0	24	0
4	0	0	0	0	2	0	10	0
5	0	0	0	0	2	0	16	0
Average	**0**	**0**	**0**	**0**	**11.2**	**0**	**13.6**	**0**

The results indicate that packet loss mainly occurs after the gateway when the train is moving, particularly at Node C and Node D. This suggests that the performance degradation is more likely caused by fluctuations in the UMTS backbone link rather than the local WiFi access network. The absence of packet loss at Node A and Node B confirms that the WiFi router and gateway device remain stable, while the increased packet loss at the external nodes reflects the impact of mobility, signal variation, and potential handover processes on the UMTS network connection. Figure 4 presents the packet loss measurement results for each test node under mobile and immobile train conditions.

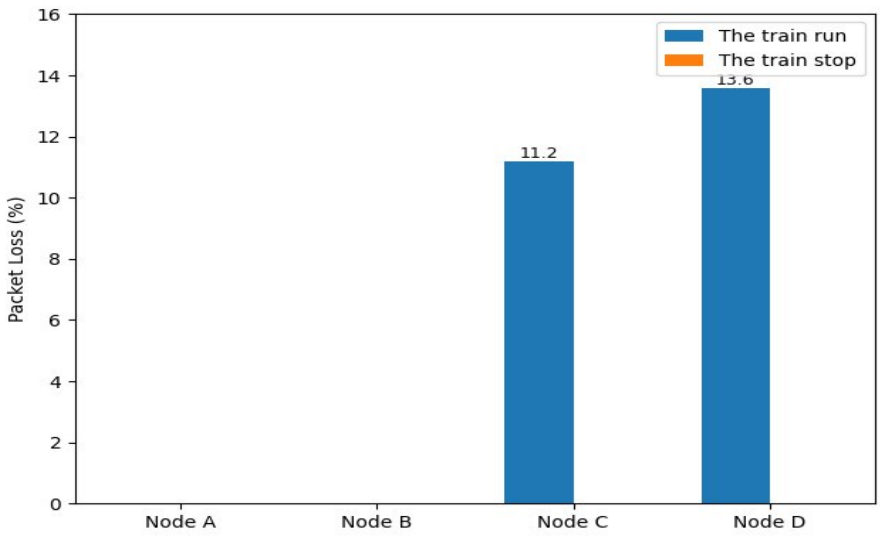


Figure 4 Packet loss measurement results

Figure 4 shows the packet loss behavior that only appears at Node C and Node D, representing end-to-end communication that relies entirely on the UMTS backbone and external networks.

Under conditions of a moving train, fluctuations in radio signal quality, decreases in Signal to Interference plus Noise Ratio (SINR), and the handover process between BTS cause temporary interruptions and packet retransmissions, which trigger packet loss in this network segment. In addition to the effects of handovers and signal fluctuations, accumulated latency and the potential for congestion on the UMTS backbone during high mobility also contribute to the increased packet loss at Node C and Node D.

Round Trip Time (RTT)

Table 5 shows the RTT measurement results. There is a very significant difference between the conditions of the train being stationary (immobile) and the train moving (mobile). At Node A (WiFi router) and Node B (internet gateway), the RTT values are relatively low and stable, with averages of 2.8 ms and 4.4 ms, respectively, under mobile conditions. The low RTT values at these two nodes indicate that the onboard WiFi network and local connections within the train have low latency and are not the main sources of network delays.

Table 5 RTT measurement results

Info	Node A		Node B		Node C		Node D	
	Mobile	**Immobile**	**Mobile**	**Immobile**	**Mobile**	**Immobile**	**Mobile**	**Immobile**
1	2	5	3	7	811	104	860	404
2	2	2	4	15	219	78	472	406
3	2	13	3	8	827	484	817	105
4	2	7	2	19	266	82	608	73
5	6	13	10	15	216	101	231	82
Average	**2.8**	**8**	**4.4**	**12.8**	**467.8**	**169.8**	**597.6**	**214**

Based on Table 5, the RTT values under mobile conditions increase significantly at Node C and Node D, with average RTTs of 467.8 ms and 597.6 ms, respectively. In contrast, Node A and Node B maintain relatively low RTT values, indicating that latency degradation mainly occurs after the gateway and is strongly influenced by the UMTS backbone performance during train movement. Figure 5 visualizes the comparison of average RTT measurements for each node under mobile and immobile conditions, highlighting the latency escalation experienced at external nodes (Node C and Node D) when the train is in motion.

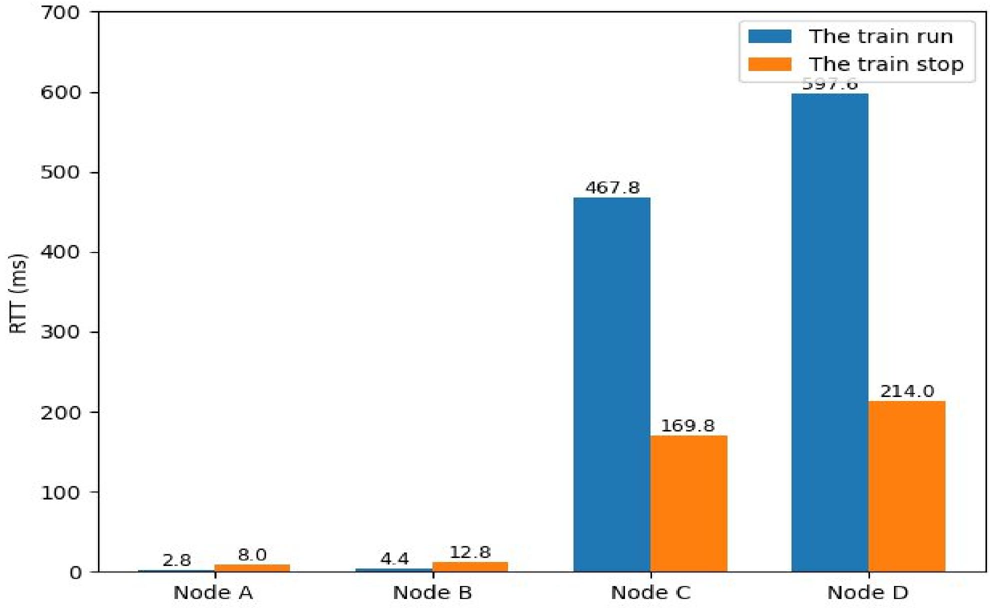
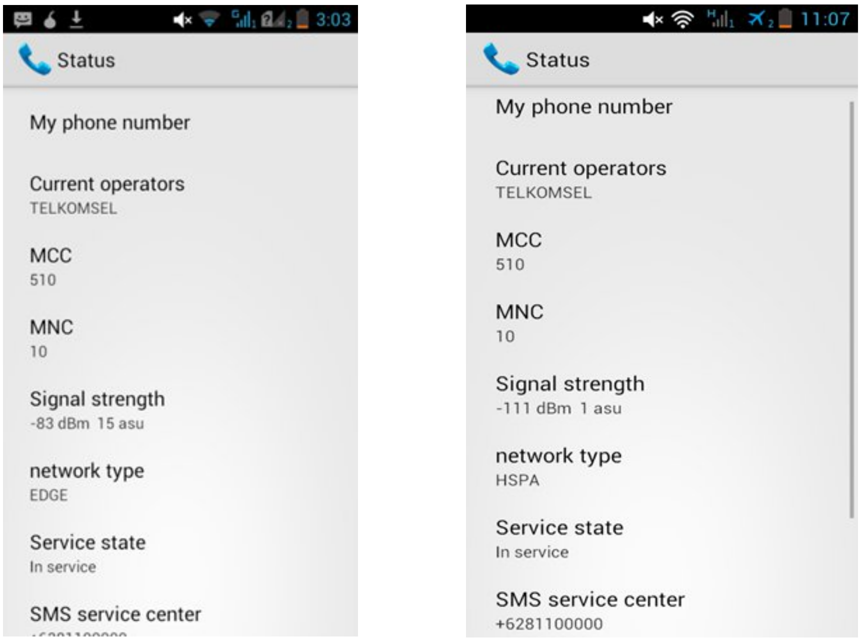


Figure 5 RTT measurement results

Conversely, a very sharp RTT escalation is observed at Node C (DNS server) and Node D (detik.com server), especially when the train is in motion. In the immobile condition, the average RTT to Node C and Node D is 169.8 ms and 214 ms, respectively, which is still within the tolerance limits for internet-based data services. However, in the mobile condition, the RTT values increase drastically to 467.8 ms for Node C and 597.6 ms for Node D. This increase indicates a significant accumulation of end-to-end delay, primarily caused by the dynamics of the UMTS backbone network in high mobility environments. Fluctuations in radio signal quality, a decrease in the Signal to Interference plus Noise Ratio (SINR), and the handover process between BTS contribute to increased queuing time, packet retransmissions, and transmission delays during cell transitions.

Measurement Results of Mobile Station Signal Strength

In the immobile condition, the signal strength received by the mobile station is relatively more stable and within a better range compared to the mobile condition. Conversely, when the train is moving, the measurement results show a decrease in signal strength reaching around −111 dBm, indicating a degradation in radio link quality during high mobility. Compared to cellular network operational standards, signal strength values below −90 dBm are categorized as unacceptable conditions. Thus, although there is signal coverage along the CL route, the analysis shows that the signal strength under mobile conditions is below an acceptable threshold, so it cannot be said to be in a “good” condition to support WiFi broadband services. This finding indicates that the radio signal quality along the route is insufficient to maintain consistent data service performance when the train is moving.



(a) Commuter line at immobile (b) Commuter line at mobile

Figure 6 Strong mobile station signal

The measurement of the mobile station signal strength shown in Figure 6a and Figure 6b indicates the difference in signal conditions when the CL is stationary (immobile) and moving (mobile).

Overall System Analysis

Measurement results show that under moving train conditions, the performance of the UMTS-based WiFi network experiences significant degradation. This is indicated by the increase in average RTT values up to 467 ms (DNS) and 597 ms (detik.com), the occurrence of packet loss ranging from 11.2% to 13.6%, as well as a decrease in throughput at nodes dependent on the UMTS backbone. Referring to the TIPHON QoS standard, these RTT values fall into the unacceptable category, indicating that the network cannot maintain adequate service quality under high mobility conditions. This finding is reinforced by measurements of the mobile station signal strength under moving conditions, which reached around −111 dBm, below the operational feasibility threshold for cellular networks (≈ −90 dBm).

Table 6 shows the MAPL link budget analysis based on the system configuration and CL environmental characteristics. TND is determined by the UMTS channel bandwidth (3.84 MHz), while a Noise Figure of 5 dB is chosen. An interference margin (3 dB) is used to model the effect of inter-cell interference, whereas a fast-fading margin (10 dB) is set to represent the effects of high mobility (≈80 km/h). Log-normal fading margin (4.2 dB) and in-car loss (8 dB) are included to model channel variations and attenuation within the train, while the soft handover gain (2 dB) represents the overlap gain of cells in the UMTS network.

Based on the gradual application of these parameters, a MAPL value of 93.7 dB was obtained, representing the maximum propagation loss that the system can still tolerate. However, field measurement results show that the actual signal strength under conditions of a moving train is far below the threshold needed to maintain a safe link margin. This discrepancy between the theoretical MAPL and the actual signal conditions consistently explains the observed increases in RTT, packet loss, and reduction in throughput in the experimental results. Thus, the link budget analysis is not only theoretical but also serves as a quantitative framework supporting the conclusion that the existing UMTS network is inadequate as a WiFi backbone on the Commuter Line with high mobility, necessitating network design improvements such as optimizing the distance/position of BTS or implementing train repeaters.

Table 6 MAPL

Info	Value	Equation
Receiver Base station		
Thermal Noise Density (dB)	-108	a
Base Station Receiver Noise Figure (dB)	5	b
Receiver Noise Density (dB)	-103	c=a+b
Receiver Noise Power (dBm)	-37.15668776	d
		d-c+10log (3840000)
Interference Margin (dB)	3	e
Total Effective noise + interference (dBm)	-34.15668776	f=d+e
Processing Gain (dB)	14.25968732	g=10log (3840/144)
Required Eb/No (dB)	1.5	h
Receiver Sensitivity (dBm)	-46.91637508	i=e+g+f
Base Station Antenna Gain (dBi)	43	j
Cable Loss in the Base Station (dB)	2	k
Fast Fading Margin (dB)	10	l
Max3 Path Loss (dB)	103.9163751	m=EIRP-i+j-k-l
Log Normal Fading Margin (dB)	4.2	n
Soft Handover Gain (dB)	2	o
In-Car Loss (dB)	8	p
MAPL (dB)	93.71637508	Q=m-n+o-p

From the MAPL results, the minimum signal strength is 89.9 dB, but the measurement results showed a value of 111 dB, which makes the existing backbone network less suitable for establishing broadband WiFi on the commuter line. Therefore, the recommendation to optimize broadband WiFi is to change the position of the BTS along the commuter line, with the placement distances as follows:

$$MAPL = 137.4 + 35.2 \log(R)$$

$$93.714 = 13.74 + 35.2 \log(R)$$

$$R = 0.05741005\ Km \cong 57.41\ meter$$

R is the range of radii that can be covered by a single BTS, so the distance between BTSs should ideally be 2R (114.82 meters). In addition, if it is not possible to change the position of the BTS, the added recommendation is a train repeater as shown in Figure 7 below.

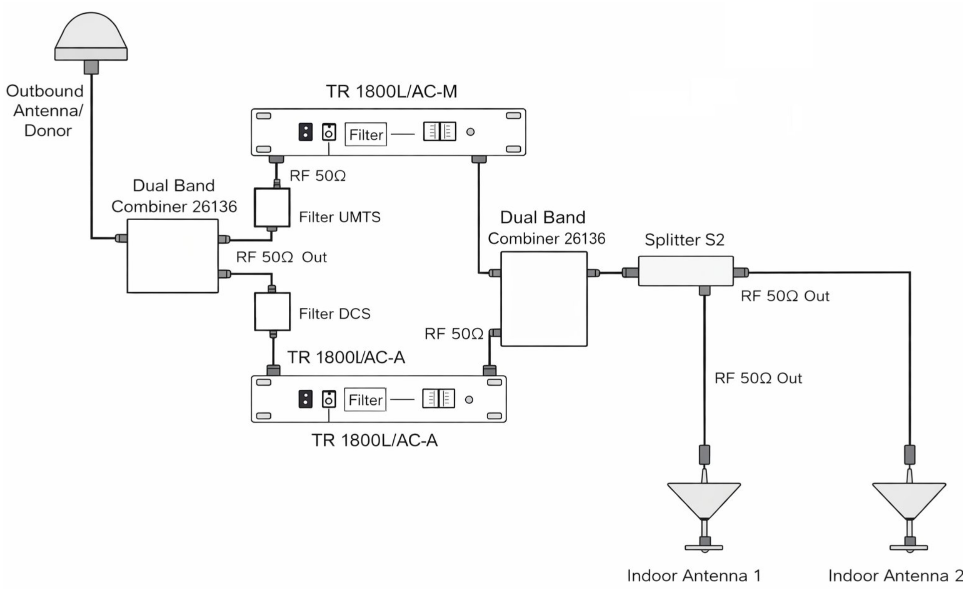


Figure 7 Wiring diagram train repeater

Figure 7 shows the wiring scheme of the train repeater used to amplify the UMTS/DCS signal from the donor antenna (outbound antenna) to the indoor distribution system. The received signal will be filtered using UMTS and DCS filters, then amplified through the TR 1800L/AC repeater device before being split using a splitter to be distributed to two indoor antennas as signal repeaters inside the train.

Conclusions

The research conclusion shows that under moving train conditions, there is a significant performance degradation in network segments relying on the UMTS backbone, marked by a decrease in end-to-end throughput of about 16.8% towards the DNS server and 12.68% towards the detik.com server, an increase in packet loss up to 13.6% and 11.2%, as well as RTT escalation of 175.50% and 179.25%, respectively. These findings are reinforced by mobile station signal strength measurements under mobile conditions around −111 dBm, far below the operational feasibility threshold (≈ −90 dBm), and consistent with link budget analysis results indicating limited propagation margin. Thus, the research objective is achieved by quantitatively demonstrating that the existing UMTS network is not yet capable of maintaining an acceptable WiFi service quality in a high-mobility Commuter Line environment. This research concludes that the analysis of QoS, signal strength, and MAPL calculation provides findings that the UMTS backbone has limitations in handover under mobile conditions. Therefore, improving WiFi service quality on CL is needed.

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