Performance Analysis of Vertical Handover Algorithm on 5G-IEEE 802.11ah Traffic Offload with Changes in Number of Nodes and Mobility

Tengku Ahmad Riza, Ajib S. Arifin, Dadang Gunawan

***Abstract*—Mobile data traffic is currently experiencing a significant and continuous increase, with no signs of decrease. This trend can impact the use of 5G mobile networks, which require high speeds and excellent Quality of Service (QoS). Therefore, service providers are expected to meet the growing demands of users and prevent connection or call failures. To address the issue as a contribution, this study proposed the use of traffic offloading integrated with vertical handover algorithm by transferring data flow from cellular to WiFi network. This study aimed to simulate algorithm under four different scenarios, namely distance, bandwidth, transmit power, and system loss. These scenarios were analyzed with respect to the influence of mobility and number of nodes, considering various QoS parameters, namely Received Signal Strength Indicator (RSSI), data rate, power consumption, throughput, and end-to-end delay rate. The simulation results showed an improvement in QoS, particularly in the RSSI parameter. The four scenarios showed that the RSSI value remained consistent despite mobility and number of nodes caused by multiple iterations of offloading between the 5G and WiFi networks. In terms of data rate parameter, the scenarios consistently showed that algorithm prioritized the highest data rate between the networks, even with user mobility conditions. It also consistently used the network with the lowest value as regards power consumption, while prioritizing the highest value in throughput. In terms of the end-to-end delay rate parameter, algorithm used the smallest value between the 5G and the WiFi networks.**

***Index Terms*— Fifth generation (5G), QoS, traffic offloading, vertical handover, Wi-Fi 802.11ah**

I. INTRODUCTION

CURRENTLY there is a growing demand for technology, particularly wireless systems catering to applications such as Ultra High Definition Television (UHD TV), Augmented Reality (AR), Virtual Reality (VR) and the Internet of Things (IoT) [1][2]. Mobile traffic typically continues to outpace non-mobile traffic (fixed traffic). Mobile data traffic using 3G, 4G, and 5G technologies is projected to reach 282 Exabite (EB) by 2027, with 60% attributed to 5G networks [5][6]. The 5G network is the most recent advancement in cellular technology, succeeding 1G, 2G, 3G, and 4G networks [7][8].

Fifth Generations networks are well-equipped to handle mobility requirements [9]. Represents a promising development, supporting over 1 million connections, offering high data rates of up to 10 Gbps, and boasting remarkably low latency of 1 ms [10][11].

Cisco forecasted that 59% of offloading traffic would occur in 2022, with 71% attributed to 5G cellular technology [11]. Some research also showed the significance of offloading traffic between cellular and Wi-Fi (Wireless Fidelity) AP (Access Point) networks [10] [11]. This strategy signifies the transfer of data from the cellular network to the Wi-Fi network [12][13] with the primary objective of reducing cellular network congestion and facilitating the preparation of access network infrastructure [14][15].

This study used the Vertical Handover Algorithm (VHOA) to analyze traffic offloading between a 5G cellular network and an IEEE 802.11ah Wi-Fi network. Handover is a process of transitioning user access from one network to another. An exemplary illustration is between cellular networks or from cellular to Wi-Fi networks, ensuring uninterrupted user connectivity. There are two main types of handover, namely Horizontal, which is the transitioning of users between cellular networks (two adjacent BTS), and Vertical, occurring when transitioning from cellular to a Wi-Fi network (between 5G and IEEE 802.11ah Wi-Fi network) [16].

IEEE 802.11 Wi-Fi represents a network standard established by the Institute of Electrical and Electronic Engineers (IEEE). The 802.11 network standard has evolved through several standards within the 802.11 family, including 802.11a, 802.11b, 802.11g, and 802.11n, operating at 2.4 GHz and 5 GHz. 802.11ax networks operate at frequencies of 2.4 GHz, 5 GHz and 6 GHz, 802.11ad networks at a frequency of 60 GHz, 802.11ah, and numerous other standards from 802.11 [17] IEEE 802.11ah Wi-Fi network specifically operates at frequencies below 1 GHz [18][19], resulting in an impressive coverage area of

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Tengku Ahmad Riza is a postgraduate student of University of Indonesia, Depok, West Java, Indonesia. (e-mail: tengku.ahmad@ui.ac.id).

Ajib S. Arifin. is an Associate Professor of University of Indonesia, Depok, West Java, Indonesia (e-mail: ajib@eng.ui.ac.id).

Dadang Gunawan is a Professor in Telecommunication Engineering at the University of Indonesia, Depok, West Java, Indonesia (e-mail: guna@eng.ui.ac.id).

up to 1 kilometer [20][21] and can support over 6000 connection stations simultaneously to the AP [22]. The proposed use of the VHOA in the 5G-WiFi IEEE 802.11ah traffic offloading network enables distribution between neighboring nodes, offering several alternative traffic flow paths to eliminate bottlenecks and minimize disconnections [22]. The proposed use of the VHOA in the 5G-WiFi IEEE 802.11ah traffic offloading network enables traffic flow distribution to neighboring nodes, offering several alternative traffic flow paths to eliminate bottlenecks and minimize disconnections.

This study established the following valuable contributions:

1. Integration of VHOA with traffic offloading in the 5G-WiFi IEEE 802.11ah network,
2. The proposed method and algorithm improved the Received Signal Strength Indicator (RSSI) QoS and reduced power consumption.
3. The proposed method and algorithm performed effectively even when the number and mobility of users changed, reducing power consumption and enhancing network QoS.

This research was structured as follows: The second section examined existing relevant research. Method, algorithm, and system modeling were discussed in Section 3. Section 4 conducted a thorough analytical performance evaluation of the proposed algorithm and modeling through simulation. Section 5 presented the conclusion.

II. RELATED WORK

Previous research analyzed traffic offloading between 3G and IEEE 802.11g Wi-Fi networks using the VHOA [23]. The analysis used NS2 and Matlab simulators, emphasizing the Received Signal Strength (RSS) parameter, handover time, and probability of blocking. Subsequently, the study was enhanced by implementing the Hybrid Algorithm in the 3G-WiFI IEEE 802.11g network. This included simulations through NS2 and analysis of power consumption, throughput, and end-to-end delay rate parameters.

To ensure Quality of Service (QoS), traffic management was conducted on Wi-Fi and cellular networks using the Quality Queue Management (QQM) Algorithm [24]. This algorithm facilitated handover decisions by predicting traffic patterns to estimate transmission probabilities on 4G cellular and IEEE 802.11ac Wi-Fi networks [25].

Fachtali et al. also aimed to minimize power consumption, reduce the time required to serve traffic flow and optimize computing time to fulfill QoS guarantees and Service Level Agreements (SLA) policies by offloading 4G and Wi-Fi cellular networks [26]. However, it was not specified which Wi-Fi standard was used. The analysis primarily focused on parameters such as Bandwidth, Security, and Power Consumption.

The study conducted by Putra et al. aimed to assess the effects of traffic offloading on the LTE and IEEE 802.11ah standards [27]. The study additionally conducted simulations to examine scenarios with a growing number of users and variable user movement rates. The primary objective was to assess the parameters of throughput and delay.

Yu et al. proposed a method for determining the dimensions of a Wi-Fi network capable of accommodating heavy users transitioning from LTE to Wi-Fi based on calculations of the remaining Wi-Fi physical channel capacity [28]. The study created a Wi-Fi network scenario comprising at least one AP serving LTE offload traffic, with additional Wi-Fi APs to reflect increased capacity.

In their study, Peddi Soumya et al. [29] put out the Energy Efficient Traffic Offloading Vertical Handover (ETOVH) algorithm as a potential solution for UMTS cellular and 802.11 Wi-Fi networks.

Chen et al. conducted a comparative analysis of traffic offloading and resource-sharing performance [30]. This included traffic offloading between the LTE base station and the IEEE 802.11n Wi-Fi AP, concluding that the traffic offloading method outperformed resource sharing.

The following conclusions were drawn from the studies:

TABLE I
Units for Magnetic Properties

Author	Traffic Offload	Cellular	Wi-Fi	Information
Budiyanto S, et al [23]	Yes	3G	802.11g	-
Pibiri G, et al [25]	Yes	4G	802.11ac	-
El Fachtali I, et al [26]	Yes	4G	802.11	-
Putra, et al [27]	Yes	4G LTE	802.11ah	-
Yu H, et al [28]	Yes	4G LTE	802.11	-
Peddi S, et.al [29]	Yes	UMTS	802.11	-
Chen Q, et.al [30]	Yes	4G LTE	802.11n	-

III. PROPOSED ALGORITHM AND SYSTEM MODELING

The network architecture integrated the concept of 5G cellular and Wi-Fi offload networks. In addition to leveraging the traffic offloading concept, this study also incorporated VHOA.

A. VHOA

VHOA is critical in deciding the occurrence of vertical handover, a choice made after considering several criteria targeted at improving QoS [31]. The parameters considered in this study included RSSI, Data Rate, Power Consumption, Throughput, and Rate End-To-End Delay.

B. Quality of Service (QoS)

Import your source files in one of the following: Microsoft Quality of Service (QoS) is a network metric utilized to assess the degree of service quality offered to user requests. In this context, an optimal network is characterized by elevated parameters. The following parameters were measured and analyzed:

- Received Signal Strength Indicator (RSSI)
  RSSI is a signal intensity indicator that measures the received signal's strength.
- Data Rate
  Data Rate indicates the typical number of bits that can be transmitted per unit of time [32]

- Power Consumption
  Power consumption denotes the amount of power used in a given time frame.
- Throughput
  Throughput is the average speed of effective data transfer, typically measured in units of bits per second (bps) [33].
- Rate end-to-end delay
  Data Rate signifies the duration a data packet requires to transmit from the source to the destination.

C. System Modeling

This study simulated the implementation of the VHOA with the aid of Matlab software, which could effectively or dynamically provide decisions to offload traffic on actual conditions.

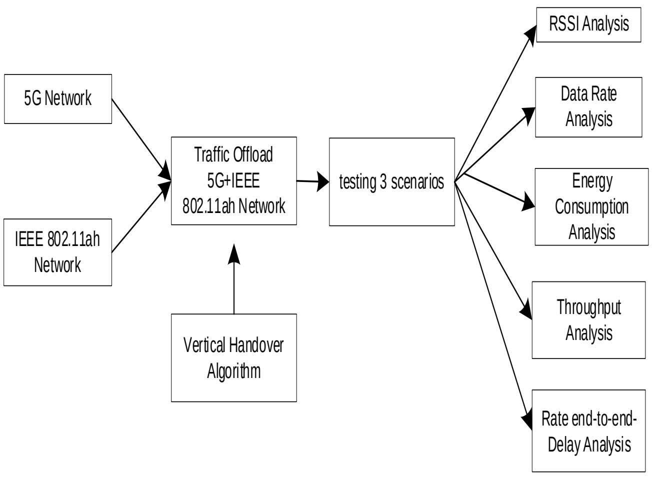

Fig. 1. System models

Figure 1 shows the system model used in this study, wherein 5G and IEEE 802.11ah networks were integrated into a single network through the incorporation of traffic offloading mechanism. This network was further enhanced by the inclusion of the VHOA, and algorithm was tested with four scenarios, namely Bandwidth, Power, Distance, and Distance with a blank spot area or with the presence of a loss system.

Figure 2 presents a flow chart that outlines the progression of this study. It begins with integrating two networks, 5G and the IEEE 802.11ah standard, which were subsequently augmented with the VHOA traffic offloading algorithm. The derived model dynamically facilitated the transition between the 5G and IEEE 802.11ah Wi-Fi network in response to and in alignment with the prevailing traffic conditions. The decision to either remain within the network or initiate handover and traffic offloading to another network was determined by predetermined scenario parameters, with a preference for the network exhibiting the most favorable specific parameters.

Several simulation and testing parameters were inputted into the Matlab software based on four predetermined simulation scenarios. The simulation could be repeated by adjusting parameter values when the initial one proved unsuccessful. Conversely, the results of RSSI, data rate, energy consumption, throughput, and rate end-to-end delay parameters could be analyzed in effective simulation. These results served as a dataset for subsequent analysis, ultimately contributing to the conclusions.

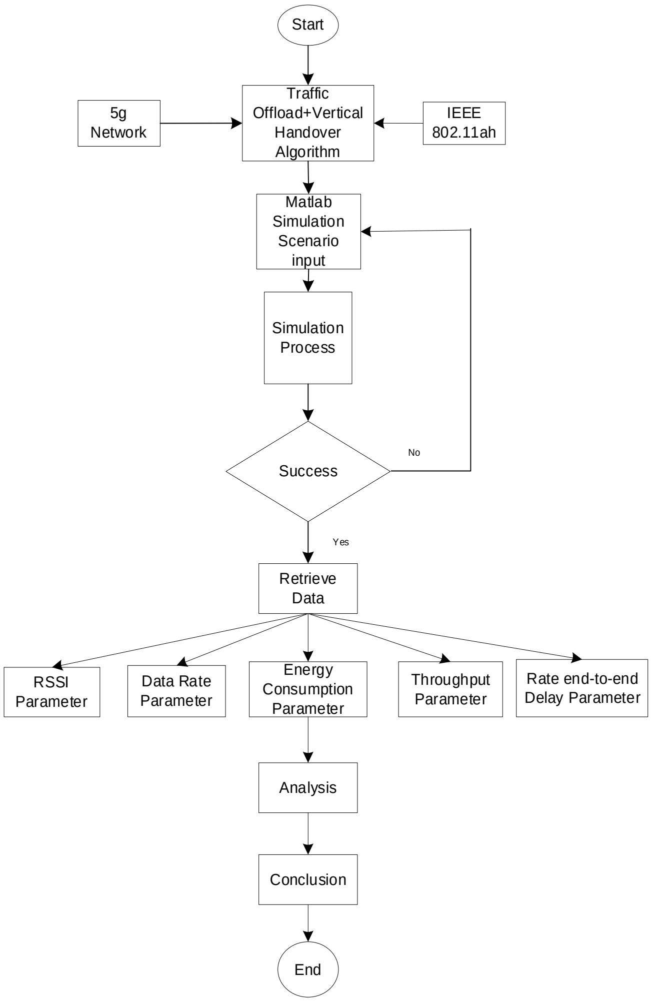

Fig. 2. Flow chart of the study

IV. SIMULATION RESULT AND ANALYSIS

This section analyzed the proposed algorithm of simulation using Matlab software. The simulation parameter settings were first analyzed and presented results about the proposed algorithm.

A. Simulation Settings

The following test scenarios were devised for evaluating the algorithm:

1. Distance Scenario
   This scenario set nodes-to-IEEE 802.11ah AP and 5G base station distances at 500m, 600m, 700m, 800m, 900m, 1000m, 1100m, 1200m, 1300m, and 1400m, with ten nodes in total.

2. Bandwidth Scenario
   This scenario used system parameters from 5G and 802.11ah networks within the Matlab library, specifically NFFT (Nonequispaced Fast Fourier Transform) with values of 15.36 MHz, 30.72 MHz, 46.08 MHz, 61.44 MHz, 76.80 MHz, 92.16 MHz, 107.52 MHz, 122.88 MHz, 215.04 MHz and 245.76MHz.

3. Transmit Power Scenario
   This scenario had variations in transmitting power, ranging from 1W to 10W.
4. System Loss Scenario
   This scenario was characterized by a loss system, specifically set at 50%.

These scenarios were simulated using input parameters for 5G and IEEE 802.11ah Wi-Fi networks. The following are the network specifications in this study:

TABLE II
5G Network Parameters

Parameter	Value
Network	5G
Frequency (MHz)	3500
Modulation	64 QAM
Antenna	8Tx2Rx
Antenna Height (m)	60
Bandwidth (MHz)	20

TABLE III
Wi-Fi Network Parameters

Parameter	Value
Wi-Fi	IEEE 802.11ah
Frequency (MHz)	>1GHz (900)
Modulation	64 QAM
Antenna	2x2
AP Height (m)	13.5
Channel Bandwidth (MHz)	2

TABLE IV
Receiver (UE)

Parameter	Value
SINR (dB)	-9
Receiver Sensitivity (dBm)	-95
Body Loss	0

The following are the specifications of the simulation scenario used:

TABLE V
Simulation Parameters

Parameter	Variable
Number of Users	10
Distance from BTS (5G) (m)	500 - 1400
Distance from AP (IEEE 802.11ah) (m)	500 - 1400
Wi-Fi Frequency (MHz)	900
5G Frequency (MHz)	3500

B. Simulation Result and Discussion

The following are the simulation and analysis results of quality of service, namely RSSI, data rate, power consumption, throughput, and rate end-to-end delay parameters.

1. Distance Scenario 1

• RSSI Parameter

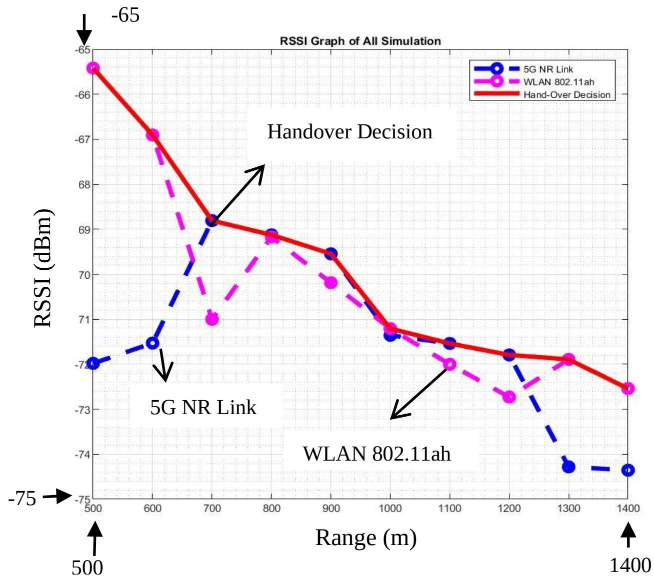

Fig. 3. RSSI Scenario 1

Figure 3 shows the implementation of the 802.11ah network within the range of 500 m and 600 m. In the 700 m range, the RSSI value of 5G was -68.81 dBm, and 802.11ah was -71.00 dBm (RSSI 5G < RSSI 802.11ah), resulting in the handover process to 5G. In the 1000 m range, the RSSI value of 802.11ah was -71.21 dBm, and 5G was -71.36 dBm (RSSI 802.11ah < RSSI 5G), resulting in handover to the 5G network. In the 1100 m range, the RSSI value of 5G was -71.54 dBm, and 802.11ah was -72.00 dBm (RSSI 5G < RSSI 802.11ah), resulting in handover to 802.11ah. Finally, in the 1300 m range, the RSSI value of 802.11ah was -71.89 dBm, and 5G was -74.28 dBm (RSSI 802.11ah < RSSI 5G), resulting in the handover process to 802.11 ah.

A total of five handovers were obtained for scenario 1 of this experiment. Fig. 3 shows the traffic offload algorithm and VHOA were run to select the best RSSI value between the two available networks, during the handover process. Furthermore, the value of the RSSI parameter generally decreased in both networks due to the transition and number of users.

• Data rate Parameter

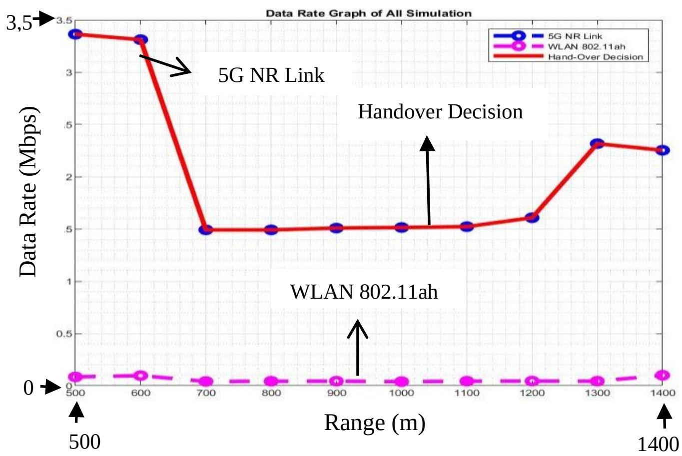

Fig. 4. Data rate Scenario 1

Figure 4 shows no handover between both networks, regardless of the data rate parameter, facilitating the prevalent use of 5G.

This experiment confirmed that the data rate parameter value of the 5G was better and higher than those of 802.11ah. Moreover, the value was influenced by both user mobility and number of nodes.

- Power Consumption Parameter

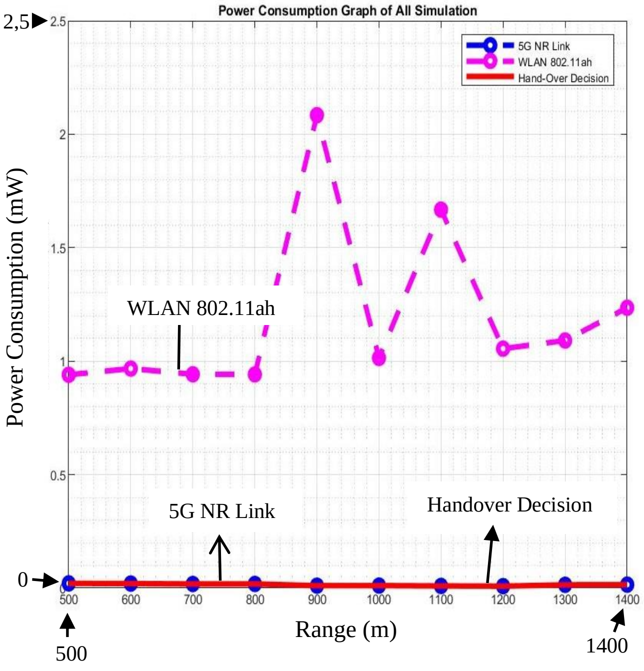

Fig. 5. Power Consumption Scenario 1

Figure 5 shows no handover process between 802.11ah and 5G, based on power consumption. Users consistently chose the network with the lowest power consumption, specifically 5G. Moreover, this parameter was influenced by distance, mobility, and number of users.

- Throughput parameter

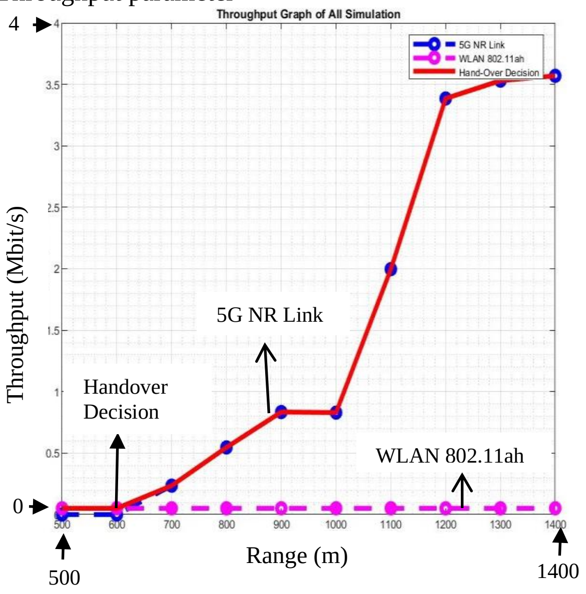

Fig. 6. Throughput Scenario 1

Figure 6 shows two instances of handover. Firstly, at a distance of 500 m, where the 5G throughput value was 0 Mbps, and that of 802.11ah was 0.05 Mbps (802.11ah Throughput > 5G Throughput), the user preferred 802.11ah. Secondly, handover process occurred from 802.11ah to 5G at a distance of 700 m, where the 5G throughput value was 0.25 Mbps, and that of 802.11ah was 0.05 Mbps (5G Throughput > 802.11ah Throughput). Fig. 6 shows how the traffic offload algorithm and VHOA run to select the network with the highest throughput. A handover and traffic offload occurred whenever the throughput of one network exceeded the other. Furthermore, the throughput values of both networks fluctuated due to mobility and the number of users.

- Rate End-To-End Delay Parameter

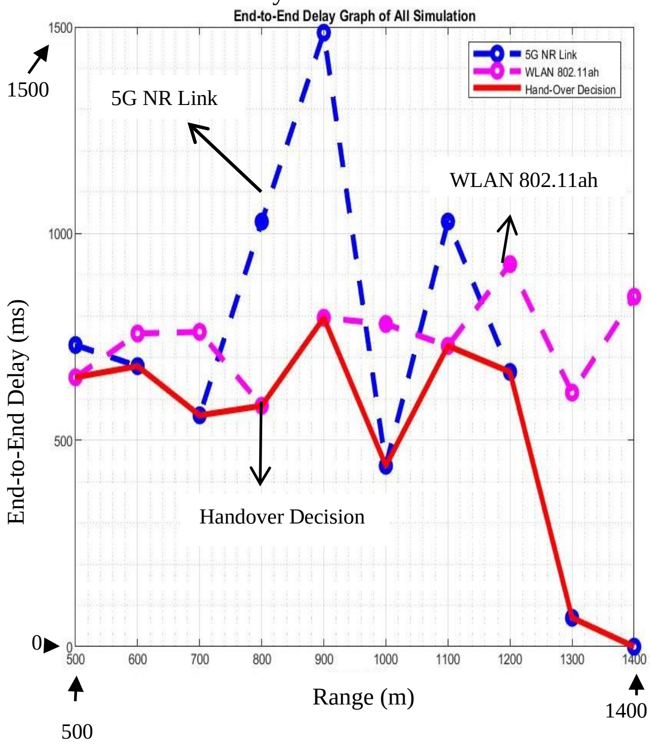

Fig. 7. Rate End-To-End Delay Scenario 1

Figure 7 shows that the 802.11ah rate end-to-end delay value at a distance of 500 m was 652 ms, while the 5G network was 730 ms (802.11ah value < 5G value), facilitating the preference for 802.11ah. As the distance between the user and the base station varied, the rate end-to-end delay value also increased, causing the user to choose the network with the smallest value. The rate end-to-end delay value for 5G at a distance of 600 m was 679 ms, and that of 802.11ah was 758 ms (rate end-to-end delay 5G < rate end-to-end delay 802.11ah), which facilitated the preference and handover to 5G. The rate end-to-end delay value of 802.11ah was 583 ms, and that of 5G was 1029 ms (rate end-to-end delay 802.11ah < rate end-to-end delay 5G) at a range of 800 m, indicating handover to 802.11ah. There were repetitions of handover process to 5G (the rate end-to-end delay value of the 5G (438 ms) < the 802.11ah network (781 ms)) at a distance of 1000 m, to 802.11ah (802.11ah value (728 ms) < 5G value (728 ms)) at 1100 m, and to 5G (5G value (665 ms) < 802.11ah value (926 ms)) at 1200 m.

The handover process was determined based on the rate end-to-end delay parameter, facilitating the preference for network with the lowest value. The selection was driven by the vertical handover and traffic offload algorithms. This parameter was influenced by the range and number of users in the experiment.

2. Bandwidth Scenario 2

- RSSI Parameter

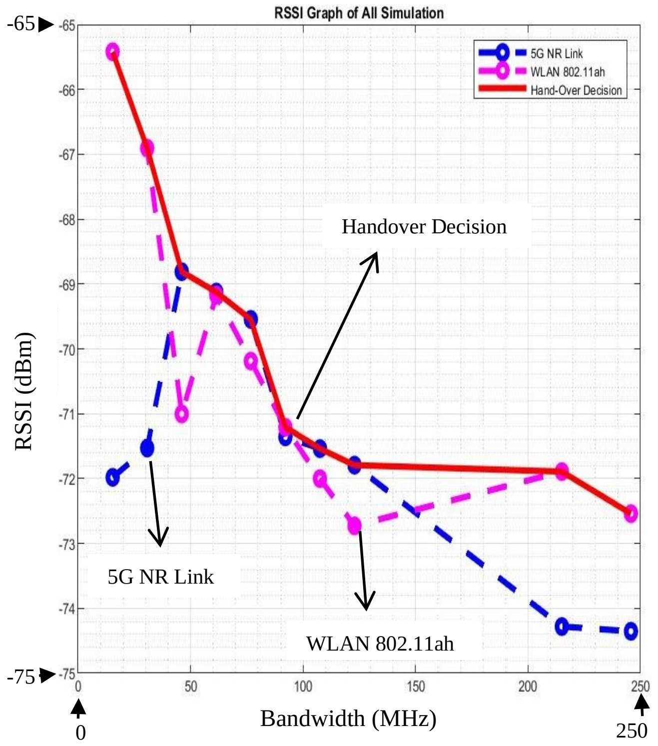

Fig. 8. RSSI Scenario 2

Figure 8 shows the relationship between bandwidth and RSSI in deciding whether to initiate a handover. The RSSI value of 802.11ah at a bandwidth of 15.36 MHz was -65.42 dBm, and the 5G network was -71.98 dBm (RSSI 802.11ah < RSSI 5G), facilitating the prevalent choice of 802.11ah. The RSSI value of the 5G network at a bandwidth of 46.08 MHz was -68.81 dBm, and 802.11ah was -71.00 dBm (5G RSSI < 802.11ah RSSI), indicating handover to 5G. Moreover, the RSSI value of the 802.11ah network at 92.16 MHz was -71.21 dBm < the 5G network of -71.36 dBm, indicating the handover process to 802.11ah. With a bandwidth of 107.52 MHz, the user would hand over to 5G since the RSSI value was -71.54 dBm < the 802.11ah network -72.00 dBm. The RSSI value of 802.11ah at 215.04 MHz was -71.8925 dBm, and 5G was -74.28 dBm (802.11ah RSSI value < 5G RSSI value), indicating handover to 802.11ah. Handover decisions were made based on the traffic offload algorithm and VHOA process by selecting the best RSSI value.

This figure shows the relationship between RSSI and bandwidth parameters, where the network with the smallest RSSI was used. Therefore, the RSSI value for both networks increased with bandwidth.

- Data rate Parameter

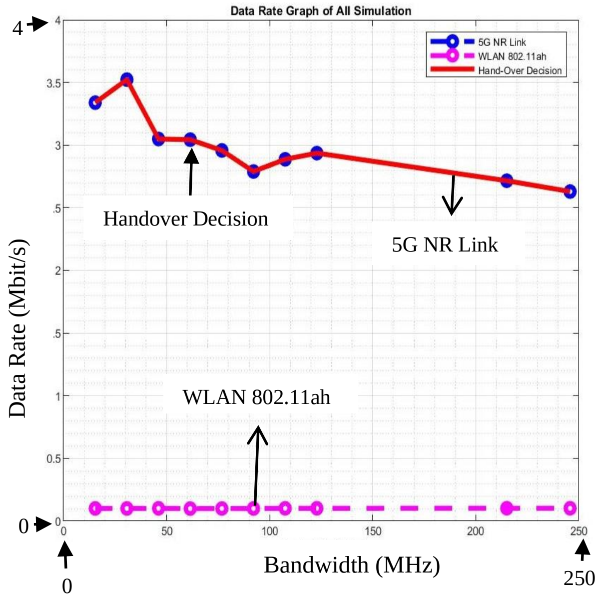

Fig. 9. Data rate Scenario 2

Figure 9 shows the decision to perform the handover process by considering the data rate and bandwidth parameters between the 5G and 802.11ah networks. There was no handover observed between 15.36 MHz and 245.76 MHz. The 5G networks had an advantage as they exhibited higher bandwidth and data rates than 802.11ah. Moreover, the relative data rate parameter decreased with an increase in bandwidth.

- Power Consumption Parameter

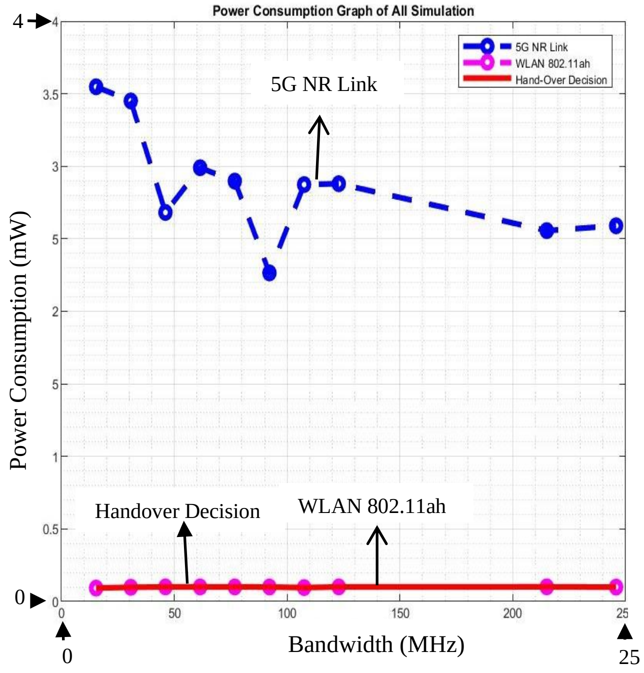

Fig. 10. Power Consumption Scenario 2

Figure 10 shows the decision to perform a handover based on the bandwidth scenario and the power consumption of the 5G and 802.11ah networks. There was no handover process in the bandwidth scenario 2 of this parameter since the users consistently used 802.11ah. This indicated the lower power consumption of 802.11ah compared to its counterpart.

- Throughput Parameter

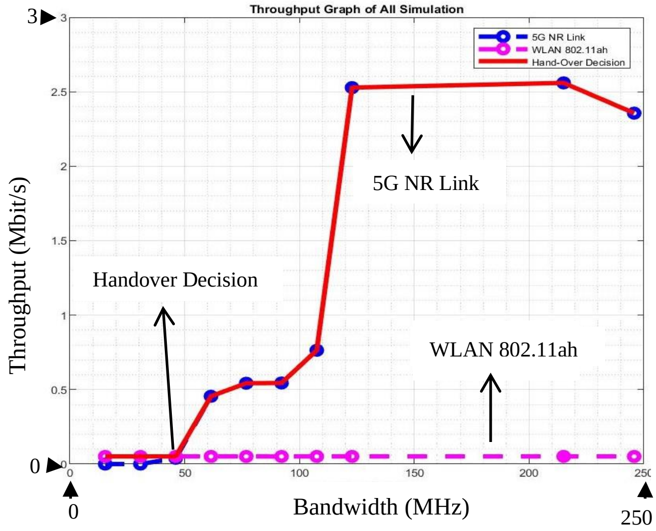

Fig. 11. Throughput Scenario 2

5G NR Link

Figure 11 shows bandwidth scenario two by considering throughput parameters as handover decision-maker. The user preferred 802.11ah at 15.36 MHz, where the throughput value of the 802.11ah network was 0.05 Mbps and 5G was 0 Mbps (802.11ah throughput> 5G throughput). The throughput value of 5G significantly increased (0.46 Mbps) compared to 802.11ah (0.05 Mbps) at a bandwidth of 61.44 MHz. Therefore, the user performed the handover process at 61.44 MHz bandwidth from 802.11ah to 5G. This indicated that the 5G cellular network offered a considerably higher throughput value. In this scenario, the traffic offload algorithm and VHOA were run to select the highest throughput value.

- Rate End-To-End Delay Parameter

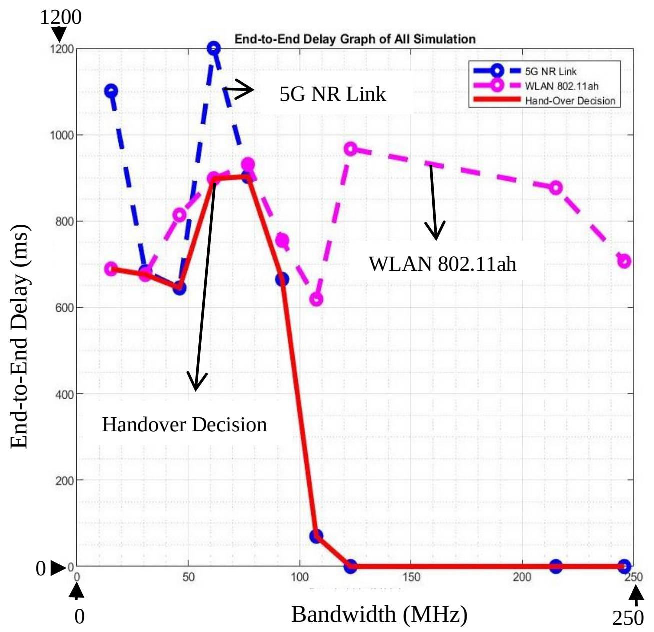

Fig. 12. Rate End-To-End Delay Scenario 2

Figure 12 shows that the rate end-to-end delay parameter of scenario 2 exhibited four handovers. The first handover occurred at a bandwidth of 15.36 MHz, where the rate end-to-end delay value of 802.11ah was 689 ms, and the 5G network was 1102 ms (802.11ah < 5G), facilitating the preference for 802.11ah. The second handover occurred at 46.08 MHz, where the delay value of 5G was 645 ms while 802.11ah was 814 ms (5G < 802.11ah), indicating handover to 5G. The third handover occurred at 61.44 MHz, with the rate end-to-end-delay value for 5G being 1200 ms, and 802.11ah being 898 ms (802.11ah < 5G), indicating handover and preference for 802.11ah. The fourth handover occurred at 76.8 MHz, where the rate end-to-end delay parameter for 5G was 903 ms, and 802.11ah was 931 ms (5G < 802.11ah), indicating handover to 5G. Users can choose the network with the smallest rate end-to-end delay value between the 5G and the 802.11ah network. This handover process occurred several times as the traffic offload algorithm and VHOA run to select the network with the lowest end-to-end delay rate. In this scenario, handover parameter rate end-to-end delay was affected by the range and number of users.

3. Power Transmit Scenario 3

- RSSI Parameter

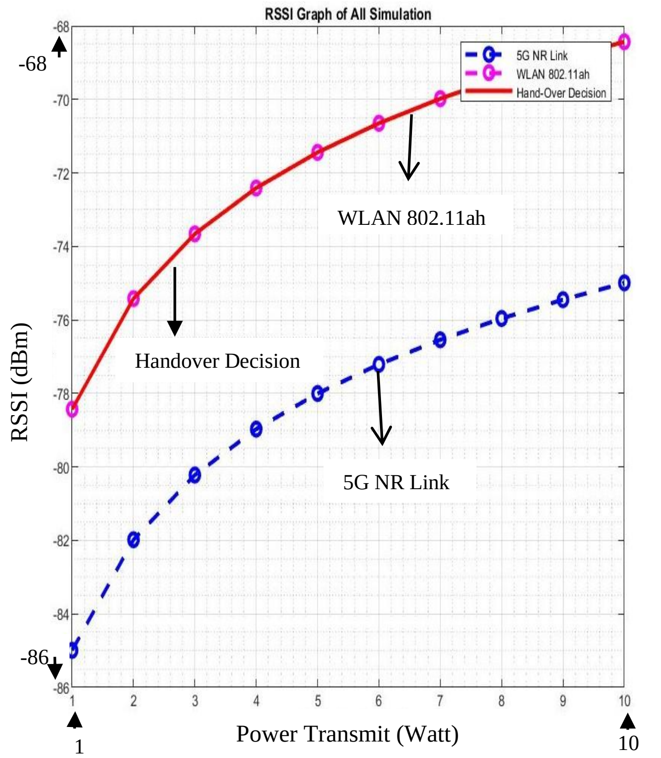

Fig. 13. RSSI Scenario 3

Figure 13 shows that no handover occurs for scenario 3 of RSSI parameters. The RSSI value at 1-watt transmit power for 5G was -84.99 dBm and -78.43 dBm for 802.11ah, facilitating the preference for 802.11ah. The IEEE 802.11ah network consistently had a better RSSI value compared to the 5G network, despite changes to transmit power in this experimental scenario.

- Data rate Parameter

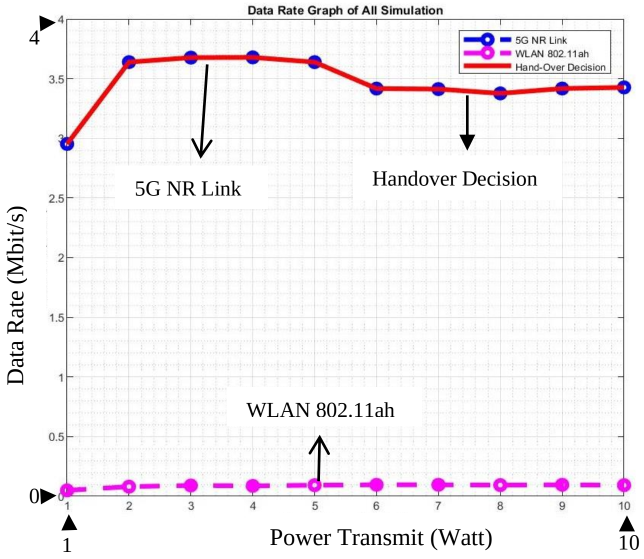

Fig. 14. Data rate Scenario 3

Figure 14 shows there is no handover process for the data rate parameter of scenario 3. The value of this parameter at 1-watt transmit power for 5G was 2.96 Mbps, and 0.05 Mbps (5G> 802.11ah) for 802.11ah, facilitating the preference for 5G. This advantage could be attributed to the higher data rate value of 5G than its counterpart. The traffic offload algorithm and VHOA did not initiate the handover process because the data rate of the 5G network remained higher than the IEEE 802.11ah network.

- Power Consumption Parameter

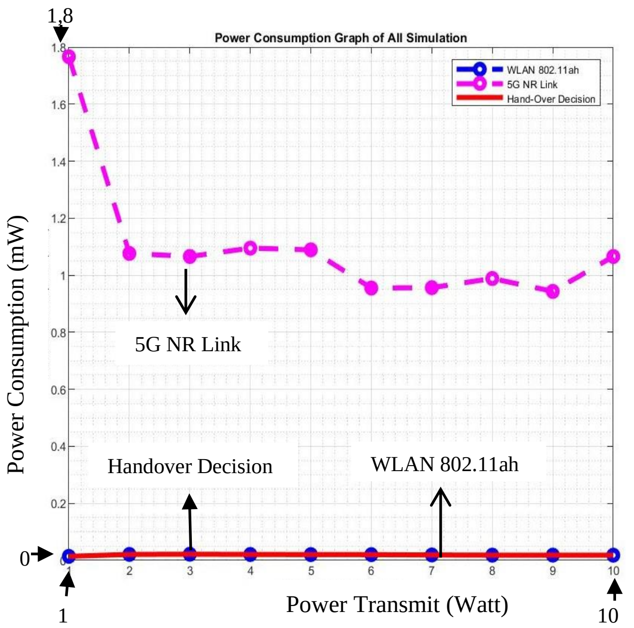

Fig. 15. Power Consumption Scenario 3

Figure 15 shows no handover process for the power consumption parameter of scenario 3. The value of this parameter at 1-watt transmit power for 802.11ah was 1.77 mW and 0 mW for 5G. Therefore, the user would prefer 802.11ah since it had a lesser value. The traffic offload algorithm and VHOA did not initiate the handover process because the power consumption of the IEEE 802.11ah network was lower than the 5G network.

- Throughput Parameter

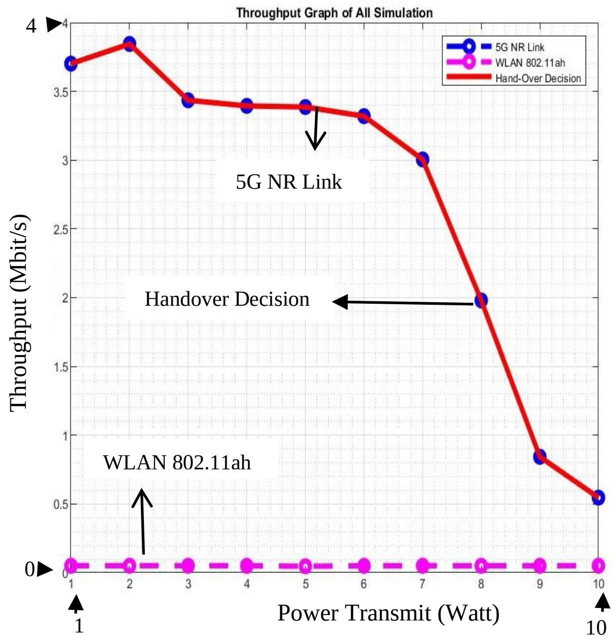

Fig. 16. Throughput Scenario 3

Figure 16 presents the throughput parameter of scenario 3 in the absence of the handover process. The value of this parameter at 1-watt transmit power for 5G was 3.70 Mbps and 0.05 Mbps for 802.11ah. Therefore, the user would prefer 5G since it had a higher value.

There was no handover process during the user simulation since the 5G throughput value consistently exceeded that of 802.11ah.

- Rate End-To-End Delay Parameter

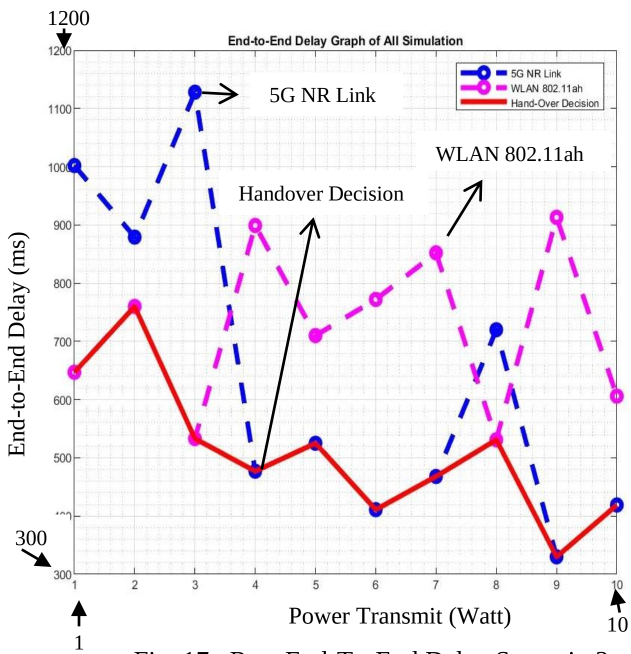

Fig. 17. Rate End-To-End Delay Scenario 3

Figure 17 shows the rate end-to-end delay parameter of scenario 3, with four distinct handovers. Firstly, the value of this parameter at 1-watt transmit power for 5G was 1002 ms and 647 ms for 802.11ah (802.11ah value < 5G value), facilitating the preference for 802.11ah. Secondly, the rate end-to-end delay value at 4 watts of transmit power for 5G

.was 477 ms, and 899 ms for 802.11ah (5G < 802.11ah), indicating handover to 5G. Thirdly, handover occurred at an 8-watt transmit power condition, where the 5G rate end-to-end delay value was 720 ms, and that of 802.11ah was 531 ms (5G> 802.11ah), indicating handover to 802.11ah. Fourthly, handover occurred at a transmit power of 9 watts, where 330 ms was obtained for 5G and 913 ms for 802.11ah (5G < 802.11ah), indicating handover to 5G. The multiple handover processes could be attributed to the traffic offload algorithm and VHOA running on the system to select the network with the lowest end-to-end delay rate.

4. System Loss Scenario 4

- RSSI Parameter

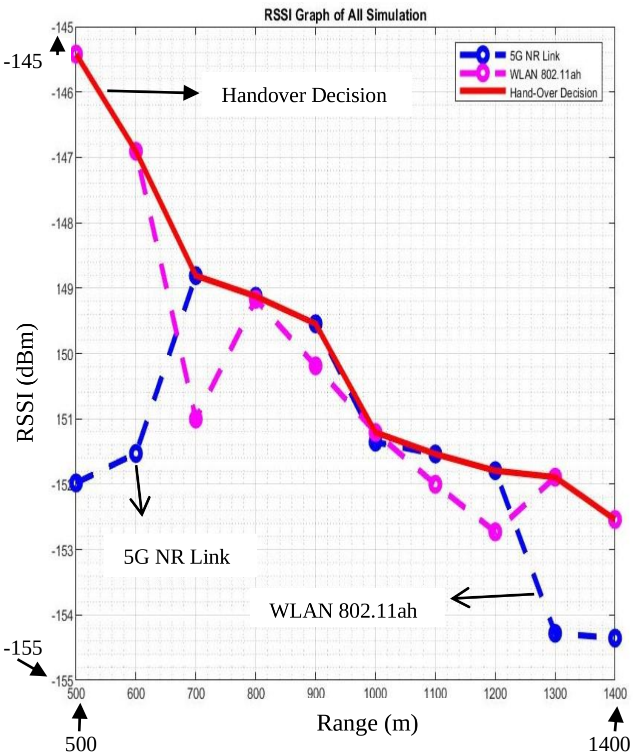

Fig. 18. RSSI Scenario 4

Figure 18 shows that the RSSI parameter of the loss system scenario experiment exhibited five handover processes. First, the RSSI value at the 500 m range for 5G was -151.98 dBm and -45.42 for 802.11ah, facilitating the preference for 802.11ah. The second handover occurred at the 700 m range, where -148.81 dBm was obtained for 5G and -151.00 dBm for 802.11ah, indicating a handover to 5G. The third occurred at 1000m range, where -151.36 dBm was obtained for 5G and -151.21 dBm for 802.11ah, indicating handover to 802.11h. The fourth occurred at a range of 1100 m, where -151.54 dBm was obtained for 5G and -152.00 dBm for 802.11ah, indicating handover to 5G. The fifth RSSI value for the 5G network was -154.28 dBm and -151.89 dBm for 802.11ah, indicating handover to 802.11ah. Therefore, several handover processes occurred. The users initiated handover to select the network with the best RSSI value, with the traffic offload algorithm and VHOA running on the system.

- Data rate Parameter

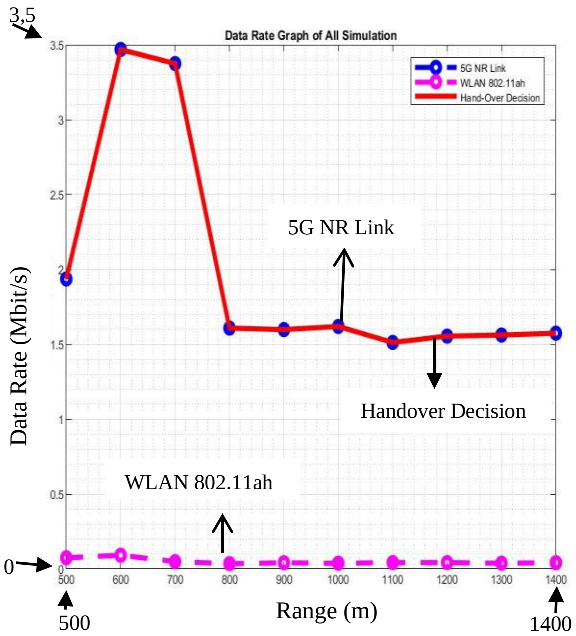

Fig. 19. Data rate Scenario 4

Figure 19 presents a data rate parameter loss system of scenario 4, with no handover process. This indicated that the 5G data rate value was better and higher than that of 802.11ah, facilitating the preference for 5G.

- Power Consumption Parameter

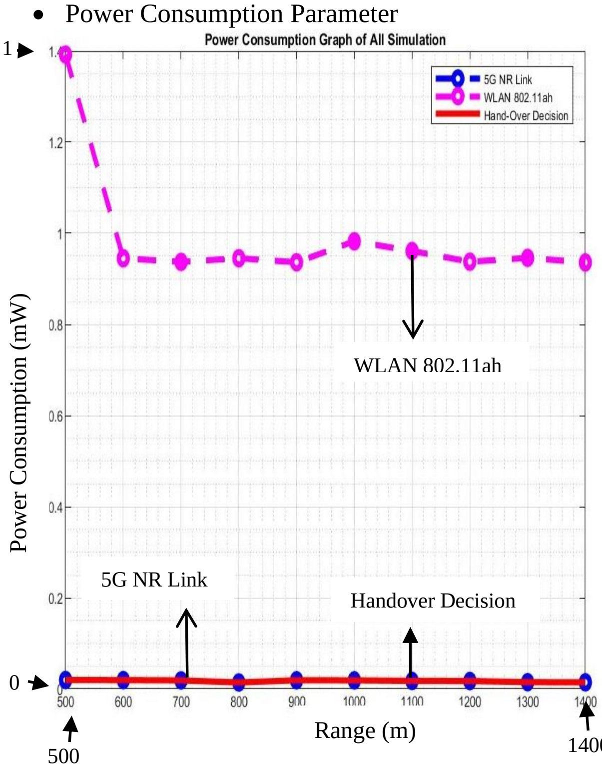

Fig. 20. Power Consumption Scenario 4

Figure 20 shows the system loss of power consumption parameter in scenario 4, with no handover process. This indicated the value of 5G was lower than that of 802.11ah, facilitating the preference for 5G.

- Parameter throughput

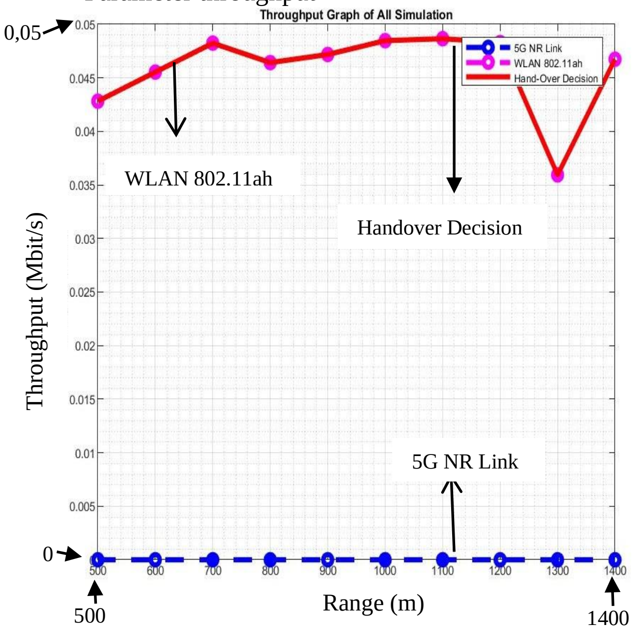

Fig. 21. Throughput Scenario 4

Figure 21 shows the throughput parameter of the loss system scenario with no handover process. The value obtained for 802.11ah was higher than that of 5G, facilitating the preference for 802.11ah with the traffic offload algorithm and VHOA running on the system.

- Rate End-To-End Delay Parameter

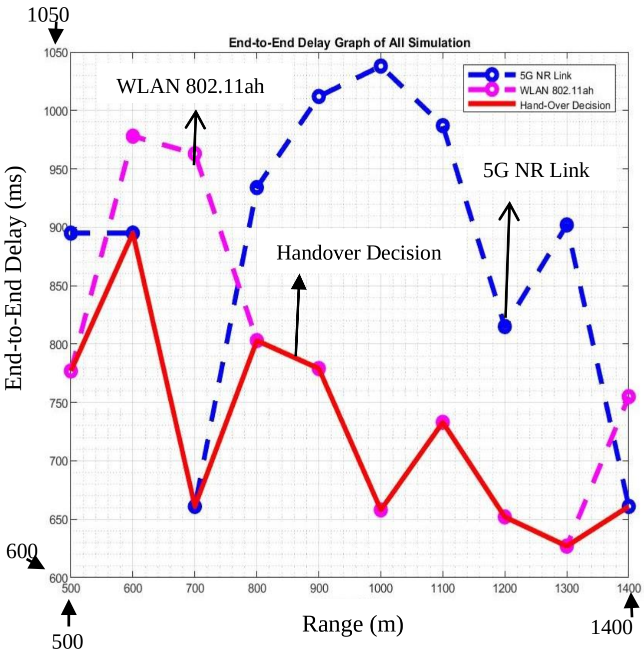

Fig. 22. Rate End-To-End Delay Scenario 4

Figure 22 shows the rate end-to-end delay parameter of scenario 4, with four distinct handovers. The first handover occurred at a range of 600 m, while the 5G and 802.11ah network end-to-end delay rate values were 895 ms and 978 ms (5G network < 802.11ah network). The second handover occurred at a distance of 800 m, the 5G network end-to-end delay rate value was 934 ms, and the 802.11ah was 803 ms (5G network > 802.11ah network). Therefore, the network moved from the 5G network to the 802.11ah. A handover occurred at a distance of 1400 m, where the 5G and 802.11ah network end-to-end delay rate values were 661 ms and 755 ms (5G network < 802.11ah network), leading to network switches to the 5G. This handover process occurred several times because the traffic offload algorithm and VHOA were run to select the network with the lowest end-to-end delay rate between the 5G and the IEEE 802.11ah networks

V. Conclusion

In conclusion, QoS parameters such as RSSI, data rate, power consumption, throughput, and rate end-to-end delay played a crucial role in determining the decision to perform traffic offloading using the VHOA between 5G and 802.11ah Wi-Fi networks. These decisions were specifically influenced by mobility and the number of users.

The 5G cellular network excelled in data rate and throughput, while 802.11ah was preferred for lower power consumption. There was also an alternation of handover and offloading between both networks for RSSI and rate end-to-end delay parameters.

The algorithm effectively selected between both networks based on the optimal RSSI, highest data rate, lowest power consumption, maximum throughput, and minimal rate end-to-end delay. Therefore, it was essential to leverage 5G mobile networks when focusing on data rate and throughput.

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