

# Multi-Criteria Handover in SDN-based Multi-RAT Networks

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**Abstract**—Beyond 5G (B5G) networks are expected to be dense, heterogeneous wireless networks that coexist within a wide range of Radio Access Technologies (RATs). Conventional handover decision mechanisms do not capture the characteristic, parametric, and performance differences associated with each coexisting RAT in the multi-RAT network. Furthermore, a single base station does not provide the management processes required to organize the cross-RAT handover decision. Software-defined networking (SDN) has the potential to be effective for Multi-RAT handover algorithm implementation. In this work, we propose a Multiple Criteria Decision-Making (MCDM) based handover algorithm in SDN-based dense multi-RAT networks. The handover decision involves the calculation of entropy-based weights for each decision criterion. The candidate nodes are ranked using the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS), which calculates the similarity of each alternative to the ideal possible and the worst possible alternative and ranks them accordingly. The chosen case study uses Mininet WiFi to implement an SDN-controlled 5G/WiFi Multi-RAT environment and uses MCDM-based handover to optimize both RSSI and delay. Results show that the proposed MCDM-based handover improves the system throughput compared to sole RSSI-based handover, in all tested cases, by at least 18%, and there is at least 43% reduction of handover failure.

**Index Terms**—5G, WiFi, Multi-RAT, MCDM, Handover, SDN

## I. INTRODUCTION

The Beyond 5G (B5G) generation of cellular networks is anticipated to provide enhanced spectral efficiency, energy efficiency, native AI integration, and continued latency and speed improvements over previous generations. B5G is also tasked with extending connectivity between and among humans, between and among machines, and a combination of both, considering various emerging technologies like industrial, agricultural, or general Internet of Things, autonomous vehicles, drones, satellites, and other types of heterogeneous network traffic. In addition, there is an immense “densification” of the cellular Radio Access Network (RAN) to accommodate the heterogeneous wireless access environment [1]. Diverse deployment scenarios with macro cells, small cells, indoor coverage solutions, and private networks, among other techniques, will enable network providers to extend network coverage and improve connectivity [1]. This co-existence of heterogeneous, multiple Radio Access Technologies (Multi-RATs) has created an ecosystem that can be leveraged to address the connectivity challenges of B5G.

Research on optimizing multi-RAT handovers is still based on the received signal strength indicator (RSSI). These approaches neglect important merits and characteristics of the surrounding networks, as well as the parametric and performance differences. Each RAT also has different propagation effects and channel constraints. A handover mechanism that uses only RSSI, and does not consider the available set of performance characteristics for quality of service and quality of experience falls short of capturing the essence of each RAT, leading to inferior handover performance. In addition, the earlier approaches, such as LTE-WiFi Aggregation (LWA) [2] and Dual Connectivity (DC) in 5G NR [3], that integrated WiFi and cellular networks to improve capacity and coverage did not provide sufficient consideration for nor leverage of the heterogeneous architectures and access venues for B5G networks. 5G NR standards use specialized entities such as Non-3GPP Interworking Function (N3IWF), to provide access to 5G’s core and access network and require additional interfaces to connect WiFi APs, for example, to the N3IWF and the N3IWF to the rest of the core and access networks [4]. Emerging research favors the use of software-defined networking (SDN) to segregate the control and data planes of each RAT, and connect each RAT through the control plane, addressing the implementation constraints of multi-RAT networks [4]–[6].

In this work, we propose a multi-RAT handover and handover performance analysis for SDN-based dense B5G multi-RAT networks. The contributions of this work are:

- A Multiple Criteria Decision-Making (MCDM) based handover algorithm is developed that involves the calculation of entropy-based weights for each decision criterion.
- Candidate nodes are ranked using the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS), which calculates the similarity of each alternative to the ideal possible and the worst possible alternative and ranks them accordingly.
- The proposed MCDM-based algorithm can offload the users to a WiFi Access Point (or satellite gateway, or other) to free up cellular spectrum so it can be allocated to other users who have critical needs.
- A Mininet implementation is created that analyzes the performance of an SDN-controlled 5G/WiFi Multi-RAT and uses MCDM to optimize both RSSI and delay.

The rest of the paper is organized as follows. Section II provides related work on SDN-based multi-RAT networks, corresponding handover methods, and the limitations associated with each approach. Section III covers the system description of the Multi RAT network and a comprehensive description of the proposed MCDM-based handover. Section V provides the details on the simulation and results of the multi-RAT network and the proposed handover method, using Mininet WiFi [7]. Finally, Section VI concludes the paper, and provides the directions for future research.

## II. RELATED WORK

### A. SDN-based Handovers in Multi RAT Networks

SDN-based cellular networks have been explored thoroughly in recent literature. SDN has been integrated into both LTE and 5G NR architectures to improve the corresponding handover control, develop efficient mobile routing, and create cellular routing policies that reduce control message exchanges [8]–[10]. However, these techniques have been restricted to the use of a single RAT.

A few studies in the literature extend the use of SDN to multi-RAT networks [5], [6], [11]. The central premise in these works is to interface multiple RATs through an SDN controller and to improve the quality of service or experience. [11] uses a hierarchical SDN controller architecture for seamless handover between WiFi, LTE, and 5G, where each controller is assumed to be able to connect with the different technologies. It uses a Distributed Hash Table to optimize coordination between the multiple controllers. The results highlight the role of SDN in improving handover processing time and reduction of the control signaling overhead. However, the mobility management method lacks specific information about the handover decision and processing phases, as well as information about the various proposed modules that facilitate the multi-RAT handover. This work precedes the current 5G standards, so it is based on the then LTE standards. There is no mention of how the delay profiles from LTE and WiFi affect the handover decision process. Next, [5] proposes an SDN-based operator-assisted offloading platform to apply to non-3GPP access technologies, e.g., WiFi or Satellite networks. There is one SDN controller for LTE and one controller for WiFi, each with a data offloading core that manages the exchange of user information. The platform is novel in using SDN to achieve WiFi offloading. However, the paper lacks crucial information about the criteria to enable the identification of compatible WiFi networks. Furthermore, more details are needed regarding how the controllers and OpenFlow switches are interfaced with the LTE base station and WIFI access point, both of which are necessary for repeating the implementation and verifying the performance of the proposed system. [6] proposes an SDN-based convergence architecture for LTE and WLAN, and virtualization-based seamless mobility-at-a-service for switching between LTE/WLAN. To avoid changing the user equipment (UE) IP address during the vertical handover, a virtual middlebox is used, consisting of virtual interfaces to create a unique IP address for a UE when

it is connected through either LTE or WLAN, which does not change until it leaves the network or becomes idle. Eliminating the IP address change avoids an interruption in services and enables a seamless handover. However, this work does not include any specifics of the handover. The authors only verify the functionality by analyzing packet transfer delay.

Several works improve handover in SDN-based 5G or cellular networks, but again very few exist in the domain of multi-RAT networks [12]. In [9], [13], handover between multi-RATs in cellular networks is discussed to be an improvement by considering factors other than RSSI, including varying bandwidth, frequencies, and dynamically varying connection delays, all of which affect the quality of service offered by each RAT. In [13], the authors address the problems with RSSI-based handovers in ultra-dense 5G small cells using an MCDM-based handover. They propose an entropy-based Simple Additive Weighting (SAW) in the handover decision phase, where the best base station for handover is selected using a weighted sum score calculated from all the available alternative base stations and their corresponding network attributes. This method is reflective of the network characteristics and can be dynamically adjusted automatically without user interference. Bandwidth, signal interference to noise ratio (SINR), and user density are considered in the handover decision phase. While simulation results are promising, the paper does not provide needed details about the procedure used for comparisons. However, the optimization process and the parameter selection provided a promising direction for this work. This work is representative of other works that use MCDM to improve the handover in cellular networks but do not consider it for multi-RAT networks. In this paper, we propose an SDN-based multi-RAT handover, to improve Handover Failure Ratio and throughput in 5G multi-RAT networks. The proposed method also demonstrates an effective offloading mechanism, by strategically handing over users from a 5G network to a different RAT. We provide the system architecture, the MCDM model, and a case study that takes into account RSSI and Delay in the handover decision phase to meet these objectives. The case study is implemented in Mininet WiFi to provide simulation results.

## III. SYSTEM ARCHITECTURE

SDN has been integrated into homogeneous mobile architectures, e.g., 4G LTE or 5G NR [8]–[10]. In addition, SDN has been considered a viable solution to connect different RATs, e.g, to connect WiFi with 4G or 5G [5], [6], [11] to simplify network management and orchestration. In this section, we describe the proposed SDN-based B5G system architecture and introduce a B5G/WiFi handover example.

SDN-based Multi RAT networks involve multiple OpenFlow-enabled switches that connect directly with the 5G base stations, called next generation Node B (gNBs) and WiFi access points (APs). Several works have outlined both research and standardized methods to connect WiFi networks with either 4G or 5G networks [5], [6], [11], [12], including our own work in [12]. Therefore, in this paper we

do not extensively cover this aspect and instead concentrate on the handover decision algorithm.

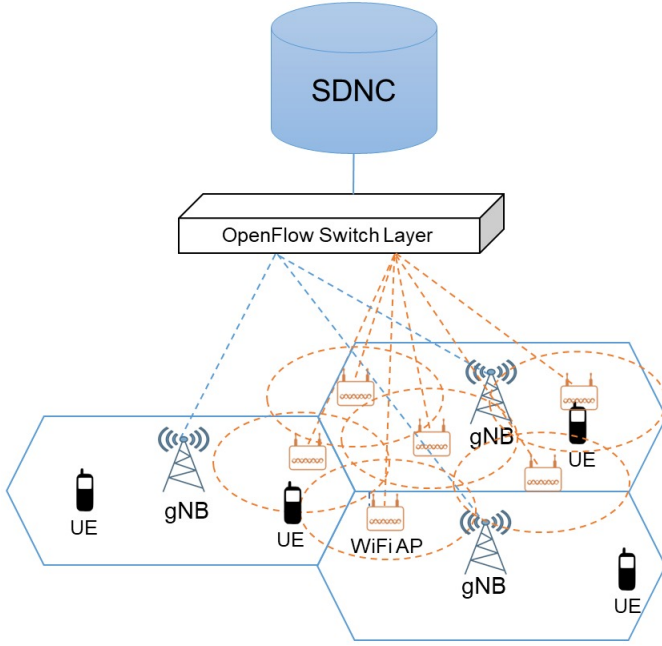


Fig. 1: SDN-based Multi RAT network architecture

Fig. 1 shows the architecture of the proposed SDN-based multi-RAT network with WiFi and 5G nodes. A single centralized SDN controller (SDNC) is used to monitor and route traffic through the OpenFlow-enabled switches in the OpenFlow-enabled switch layer. The gNBs and the WiFi APs are connected to the OpenFlow-enabled switches, which forward their packets to/from the SDN controller. Each switch is considered to be compatible with each of the respective gNBs and APs. The ingress packets at the switch are routed to the corresponding destinations after matching with the flow tables in each switch. In the case where there is no flow rule for an ingress packet, the packet is sent to the SDN controller to record its destination. The controller updates the destination of the packets as a flow rule, which is installed into all the switches connected to the SDN controller. From the next instance, such an ingress packet is automatically routed via the switches via the corresponding flow rule.

The UEs are assumed to be capable of using both WiFi and 5G RATs [14]. The RSSI of each UE is measured and compared with respect to the APs in its coverage area. The average link delay can be collected periodically to facilitate an MCDM-based handover. While handover optimization and mobility management applications can occur on the SDN controller, the required modification of the OpenFlow messages, e.g., as seen in [13], is beyond the scope of this work. So, in this work SDN is used to provide the interconnection between the two RATs at the IP level and to optimize the packet forwarding, as in [8], [9].

#### IV. MCDM BASED MULTI-RAT HANDOVER

MCDM involves two main steps: (1) obtaining criterion weights and (2) decision-making [15], [16]. To obtain criterion weights, the entropy-based weighting method is used, where entropy reflects the amount of information preserved within or the variation in the range, and then entropy-based weighing compares the relative information present in each criterion and assigns a proportional weight. Smaller entropy means a larger range of information and variation in the criteria, warranting a larger relative weight to the respective criterion. Conversely, larger entropy means a smaller amount of information, or a smaller range of the values within a criterion, warranting a smaller relative weight. Once the weights are obtained, the next step is to decide the best AP from the available candidates. For this step, we use the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) to rank the alternatives. TOPSIS is an MCDM method used to rank a set of alternatives based on their similarity to an ideal solution and dissimilarity from a negative solution. The ideal solution represents the best values for each criterion, while the negative solution represents the worst values. The alternatives that are closer to the ideal solution and farther from the negative solution are ranked higher. TOPSIS has been used previously in network selection problems [15], [17].

##### A. MCDM for 5G/WiFi, RSSI and Delay

The objective of this work is to attempt to use Multi-RAT handover to fulfill the B5G goal of limiting the costly usage of 5G cellular resources whenever possible, and to reduce the incidence of failed handovers. The steps involved in the conventional handover are the collection of the RSSI measurements from the nodes in range and the selection of the node with the highest RSSI as the target node. Finally, the radio link is transferred to the target node. It has been shown that the handover decision can be improved if other network parameters that impact the QoS are considered along with the RSSI [9] [13]. This improvement is valid for multi-RAT networks, with added complexity. For example, between gNB and AP targets, the gNB would have the strongest transmit power, so it would always be selected as the target node despite the WiFi APs having significant enough RSSI to support the UE without affecting the throughput. This result would be in opposition to one of the objectives of this work, which is to show that we can offload the UEs to an AP (or satellite gateway, or other) node to free cellular spectrum so it can be allocated to other users who have critical needs. The weights can assist in adjusting the target choice according to the prioritized algorithm.

In addition to the RSSI, we consider the link delay, which indicates the latency in the link, for selecting the best node as the target node for the UE. The two parameters capture the influence of distance between the user and the gNB/AP, propagation, and environmental conditions. Considering additional parameters is beyond the scope of this paper due to time and page constraints. We provide a case study using RSSI and delay obtained from the UE with respect to the APs and the

gNBs in its range. MCDM is used to decide on the best target node. We apply our proposed multi-RAT handover algorithm to the following handover cases: (1) from WiFi to 5G, (2) from 5G to WiFi, and (3) from WiFi to WiFi. The entropy-based weighing method assigns a larger weight to the RSSI criterion, only if the range of the RSSI values of UE at an AP, is larger than the corresponding range of the delay values. To avoid the gNB strongest RSSI issue, when the gNB is selected from the algorithm, the next best alternative to the gNB is selected as the target.

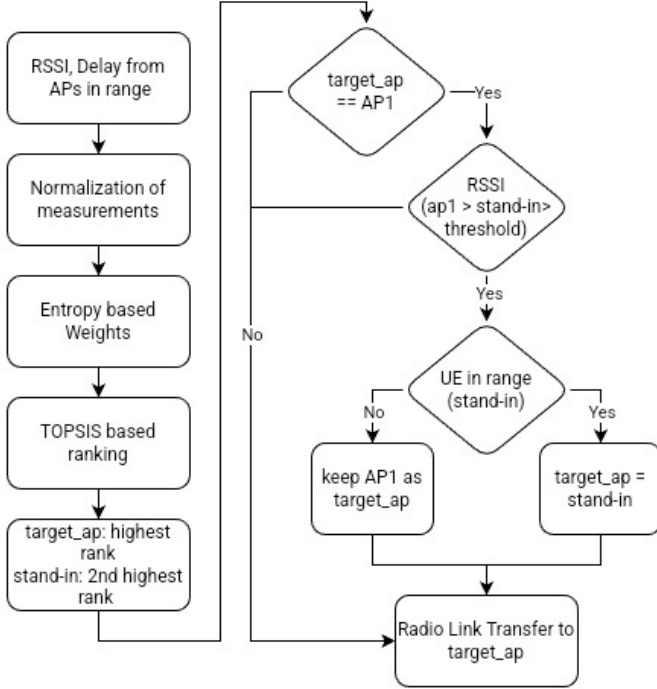


Fig. 2: MCDM based user-specific handover algorithm

The proposed MCDM-based Handover using Entropy-based TOPSIS is shown in Figure 2. First, we collect all APs in the range of a UE. The gNB is also included in the nodes if the UE falls into its coverage area. This serves as the list of possible targets for the handover decision phase. The corresponding RSSI and delay values are collected for each possible target, and form the decision matrix for the MCDM method. The obtained decision matrix is normalized and the entropy values for each criterion are calculated to obtain the criterion weights. Next, TOPSIS is used to rank the available alternatives based on the Euclidean distance of each alternative from the best and worst possible alternatives respectively. The highest-ranking alternative from TOPSIS will have the least distance from the best possible alternative and the highest distance from the worst possible alternative respectively. The highest-ranking alternative is selected as the "target", while the second-ranking alternative is selected as the "stand-in". The following comparisons are made to strategically move the UE to a WiFi network when the target is the gNB. If the target obtained from MCDM is the gNB, the RSSI value of

the stand-in is checked. If the RSSI of the stand-in is greater than a predetermined threshold, say -80dB, and the UE is within range of the stand-in, then the algorithm chooses the stand-in, i.e., an AP instead of the gNB. Finally, the radio link transfer to the selected target is initiated. These steps enable the strategic selection of a node other than a gNB to free up the 5G spectrum. Furthermore, the UE is connected to a link with better delay and RSSI combined, improving the latency of the connection to provide users with a better Quality of Service.

## V. SIMULATION AND RESULTS

The objective of the proposed handover is to facilitate the offloading of users onto WiFi nodes while improving the throughput and reducing the number of failed handovers. Moreover, the proposed handover also considers RSSI and delay, to provide the UE with better latency associated with the connection delay. The system is simulated using Mininet WiFi and the following parameters are collected to verify the described objectives.

- **Handover Failure Ratio:** The total number of handover failures to the total number of handover attempts, including two cases: (1) failure to connect to the MCDM target node (even though still connected to the original node) and (2) failure to connect to target node and disconnection from current node, so that the connection is dropped.
- **Throughput:** The amount of data transferred over a link in a given time is collected after each handover attempt. (A failed handover results in approximately zero throughput.) The values are collected across the network simulation time and the cumulative throughput is used to compare the MCDM and conventional handovers.
- **Delay Difference:** The difference in the UE's delay values at the target node and the current node. A negative value indicates that the delay associated with the target node is lower than that associated with the current node. Conversely, a positive value means that the UE's connection with the target node has a higher delay compared to that with the current node.

### A. Multi-RAT network simulation

The architecture described in Section III is realized using the RYU controller and Mininet WiFi emulator. The SDN RYU controller is an open-source Python-based SDN controller used to run an L3 switch, which implements a IP-based packet matching. Mininet WiFi is an extension of the Mininet emulator, which is a widely used tool for wired SDN research. Mininet WiFi provides support for wireless integration of the SDN controller with the WiFi access points through OpenFlow-enabled switches. There is no inherent support for cellular technologies such as LTE and 5G NR, so custom modifications were made to Mininet WiFi to create nodes similar to gNBs. Table I gives the network parameters used for each RAT. For gNBs the frequency of operation was set to 2.412GHz, and the transmit power was calculated using 3GPP's Non-Line of Sight Urban Macro Model for 5G NR

[18]. Mininet WiFi uses generic propagation models that use path-loss exponents to calculate the RSSI at the receiver. So, the calculated transmit power and range using the 5G NR standards are mapped to the range of possible values within the urban mobility model [19], and the Log Normal propagation model with a path loss exponent of 3.5 is selected. In the case of the WiFi APs, the frequency of operation is set to 5GHz, and the 802.11 ax standard is used.

TABLE I: Mininet WiFi parameters for Multi RAT network simulation

| Parameter         | WiFi AP       | 5G BS     |
|-------------------|---------------|-----------|
| Frequency         | 5.18-5.825GHz | 2.412GHz  |
| TxPower           | 2dBm          | 16dBm     |
| Range             | 60m           | 150m      |
| Mode              | ax5           | g         |
| Propagation Model | LogNormal     | LogNormal |
| Pathloss exponent | 3.5           | 3.5       |

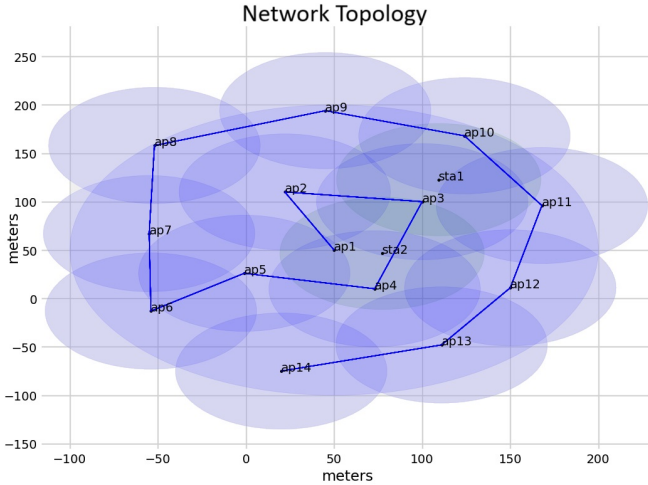


Fig. 3: Simulated Multi RAT network with 2 mobile UEs

The topology consists of one gNB and 14 APs, with the APs evenly distributed across the coverage area of the gNB. An increasing number of UEs is distributed randomly across the topology. Each UE follows the "random direction" mobility model, defined in Mininet WiFi. Each simulation run is carried out with 2, 4, and 16 UEs to mimic a densely populated urban environment. Fig. 3 shows the simulated network topology with 2 UEs denoted as 'sta', gNB at the center of the large coverage area, denoted by 'ap1', and 14 WiFi APs, denoted as 'ap2-ap15'. A hard handover is used in Mininet WiFi, i.e., the connection to the existing node is dropped before the radio link is transferred to the target node. Using this topology, the simulation is repeated for both the proposed MCDM-based handover and a conventional RSSI-based handover, as described in section IV for a predetermined time duration, 30 minutes. Each algorithm is run three times.

## B. Numerical Results

Fig.4 shows the average of the three individual runs for each topology and algorithm. In the figure, MCDM refers to the proposed MCDM-based handover and RSSI refers to the conventional RSSI-based handover. The results show that the proposed MCDM-based handover performs better than the conventional method for all three cases, across all performance metrics. As seen in Fig. 4a, HFR for the proposed MCDM-based handover is always lower than the RSSI-based handover. There is at least 43% reduction of HFR compared to the conventional handover. This is due to the MCDM approach, which calculates the criterion weights based on the entropy within collected measurements, and uses TOPSIS to determine the best target node, which is closest to the ideal choice and farthest from the worst choice available. Fig. 4b provides insights into the throughput obtained using the MCDM and RSSI-based handover algorithms. As the number of UEs increases, the throughput obtained across MCDM and RSSI-based handovers increases. It can be seen that MCDM improves the throughput compared to RSSI-based handover, in all cases, by at least 18%. This can also be attributed to the combination of an entropy-based weighing scheme and TOPSIS for the MCDM-based handover.

Fig. 4c shows that the MCDM-based handover results in a significantly lower delay compared to an RSSI-based handover. This is expected, as the RSSI-based handover does not consider delay during the handover decision phase. The negative value of the delay difference means the target node offered a lower delay than the current node. The results show that the MCDM handover reduces the delay difference by 4.75 msec, 12.74 msec, and 48.66 msec in the case of 2, 4, and 16 stations respectively. In the case of 16 stations, the throughput is 64% greater than that of the RSSI-based handover, combined with a 48.66 msec reduction in the delay difference. This shows the proposed method outperforms the traditional RSSI-based handovers for reducing link delay during handover and effectively improving the QoS offered to the UEs.

As described in Section IV, the MCDM handover computes a "stand-in" node when the target node is determined as the 5G gNB. This is done to strategically offload UEs from 5G to WiFi, to free up 5G spectrum for higher priority purposes. Fig. 4 demonstrates that strategically selecting the WiFi nodes over 5G BS has no negative impact on the HFR or throughput. Selecting WiFi nodes can contribute to an increase in total handover attempts, leading to the possibility of increased handover failures. However, according to Fig.4a, the HFR of the proposed MCDM-based handover is always lower than the RSSI-based handover. This indicates that the handovers are successful despite the increased handover attempts due to the strategic WiFi offloading, resulting in a low overall HFR. Thus, the proposed MCDM-based handover also provides an efficient WiFi offloading approach.

## VI. CONCLUSION AND FUTURE WORKS

Multi-RAT networks have different RAT-specific characteristics such as varying bandwidths, frequencies of operation,

and latencies. Traditional RSSI-based handovers fall short of taking into account such diverse characteristics while deciding the best network to hand over a user to. In this paper, we propose an MCDM-based handover for SDN-based Multi-RAT networks. The proposed MCDM method uses entropy to determine the relative importance of each criterion and uses TOPSIS to rank all the available nodes. Experimental results show that the proposed MCDM-based approach performs better than conventional RSSI-based selection, by reducing the Handover Failure Ratio by at least 43%, providing the least delay difference, and improving throughput by 18%.

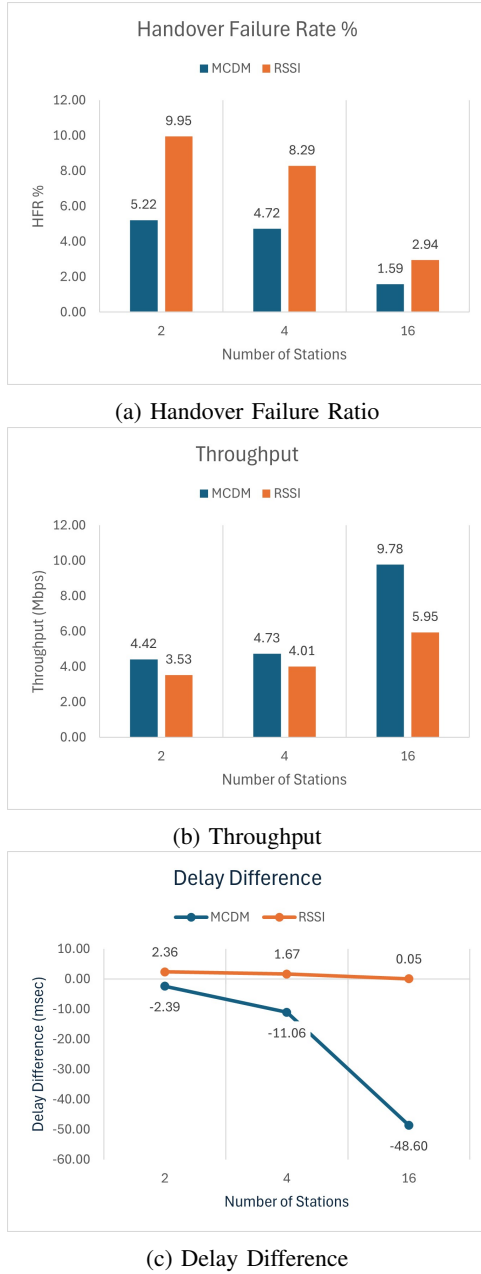


Fig. 4: Performance metrics comparison of MCDM and RSSI based handover

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## REFERENCES

- [1] Syed Muhammad Asad Zaidi, Marvin Manalastas, Hasan Farooq, and Ali Imran. Mobility management in emerging ultra-dense cellular networks: A survey, outlook, and future research directions. *IEEE Access*, 8:183505–183533, 2020.
- [2] Apostolos Galanopoulos, Fotis Foukalas, and Theodoros A Tsiftsis. Efficient coexistence of lte with wifi in the licensed and unlicensed spectrum aggregation. *IEEE Transactions on Cognitive Communications and Networking*, 2(2):129–140, 2016.
- [3] Osman NC Yilmaz, Oumer Teyeb, and Antonino Orsino. Overview of lte-nr dual connectivity. *IEEE Communications Magazine*, 57(6):138–144, 2019.
- [4] Meghna Khaturia, Pranav Jha, and Abhay Karandikar. 5g-flow: A unified multi-rat architecture for beyond 5g networks. *Computer Networks*, 198:108412, 2021.
- [5] Madhusanka Liyanage, Mahesh Dananjaya, Jude Okwuibe, and Mika Ylianttila. Sdn based operator assisted offloading platform for multi-controller 5g networks. In *2017 IEEE International Symposium on Local and Metropolitan Area Networks (LANMAN)*, pages 1–3. IEEE, 2017.
- [6] Luhan Wang, Zhaoming Lu, Xiangming Wen, Gang Cao, Xiuyan Xia, and Lu Ma. An sdn-based seamless convergence approach of wlan and lte networks. In *2016 IEEE Information Technology, Networking, Electronic and Automation Control Conference*, pages 944–947, 2016.
- [7] Ramon R. Fontes, Samira Afzal, Samuel H. B. Brito, Mateus A. S. Santos, and Christian Esteve Rothenberg. Mininet-wifi: Emulating software-defined wireless networks. In *2015 11th International Conference on Network and Service Management (CNSM)*, pages 384–389, 2015.
- [8] Jonathan Prados-Garzon, Oscar Adamuz-Hinojosa, Pablo Ameigeiras, Juan J Ramos-Munoz, Pilar Andres-Maldonado, and Juan M Lopez-Soler. Handover implementation in a 5g sdn-based mobile network architecture. In *2016 IEEE 27th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, pages 1–6. IEEE, 2016.
- [9] Jacky Rizkallah and Nadine Akkari. Sdn-based vertical handover decision scheme for 5g networks. In *2018 IEEE Middle East and North Africa Communications Conference (MENACOMM)*, pages 1–6. IEEE, 2018.
- [10] Abdulaziz Abdulghaffar, Ashraf Mahmoud, Marwan Abu-Amara, and Tarek Sheltami. Modeling and evaluation of software defined networking based 5g core network architecture. *IEEE Access*, 9:10179–10198, 2021.
- [11] Ali Saeed Dayem Alfoudi, S. H. Shah Newaz, Rudy Ramlie, Gyu Myoung Lee, and Thar Baker. Seamless mobility management in heterogeneous 5g networks: A coordination approach among distributed sdn controllers. In *2019 IEEE 89th Vehicular Technology Conference (VTC2019-Spring)*, pages 1–6, 2019.
- [12] Pavan K Mangipudi and Janise McNair. Sdn enabled mobility management in multi radio access technology 5g networks: A survey, 2023. Last accessed on April 14, 2024 at <https://arxiv.org/abs/2304.03346>.
- [13] Murtaza Cicioğlu. Multi-criteria handover management using entropy-based saw method for sdn-based 5g small cells. *Wireless Networks*, 27(4):2947–2959, 2021.
- [14] Wenye Wang, Janise McNair, Xin Wang, and Y.K. Yoon. Poster: Nsf swift: A spectrum orchestrating control plane for co-existing wireless systems. In *National Science Foundation Spectrum Week*, April 2023.
- [15] Maroua Drissi and Mohammed Oumsis. Multi-criteria vertical handover comparison between wimax and wifi. *Information*, 6(3):399–410, 2015.
- [16] E. Triantaphyllou. *Multi-criteria Decision Making Methods: A Comparative Study*. Applied Optimization. Springer US, 2013.
- [17] Mohamed Abdelkrim Senouci, M. Sajid Mushtaq, Said Hoceini, and Abdelhamid Mellouk. Topsis-based dynamic approach for mobile network interface selection. *Computer Networks*, 107:304–314, 2016. Mobile Wireless Networks.
- [18] ETSI. *ETSI TR 138 901 V16.1.0 (2020-11): 5G; Study on channel model for frequencies from 0.5 to 100 GHz (3GPP TR 38.901 version 16.1.0 Release 16)*, November 2020. Last accessed: February 24, 2022.
- [19] A. Goldsmith. *Wireless Communications*. Cambridge Core. Cambridge University Press, 2005.