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Data Rate-Aware Predictive Inter-Cell Handoff Technique for IEEE 802.11 Wireless Networks

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Abstract

Seamless handoff remains a critical challenge in IEEE 802.11 wireless networks, particularly in dense and highly mobile environments where conventional reactive handoff mechanisms based primarily on Received Signal Strength (RSS) may trigger decisions only after significant degradation in link quality. Recent studies have demonstrated the potential of Machine Learning (ML), edge computing, and Software-Defined Networking (SDN) to improve handoff prediction, reduce unnecessary handovers, and enhance throughput. However, existing approaches largely emphasize handoff latency, success rate, Signal Strength (SS), or general throughput optimization, while the prediction of impending handoff based on the expected Data Rate (DR) of the serving and neighbouring Access Points (APs) remains insufficiently explored. This limitation is significant because a reduction in RSS does not necessarily imply an immediate deterioration in achievable DR, and an AP with stronger SS may provide lower effective DR because of congestion, interference, channel conditions, or resource utilization. This study therefore presents a predictive inter-cell handoff technique for IEEE 802.11 wireless networks that incorporates data-rate trends into the handoff decision process. The method continuously monitors historical and real-time network parameters, with particular emphasis on the user's current and predicted DR, to anticipate service degradation before it becomes critical. By predicting the future data-rate condition of the serving cell and comparing it with candidate neighbouring cells, the technique aims to identify an appropriate handoff opportunity proactively rather than waiting for conventional threshold-based degradation. The approach reduces unnecessary handoffs, minimizes service interruption, and maintains a more stable and higher-quality DR during user mobility. Consequently, the study addresses a key gap in existing IEEE 802.11 handoff mechanisms by shifting the decision criterion from predominantly signal-strength-based handoff toward data-rate-aware predictive handoff, providing a basis for more reliable mobility management and improved Quality of Service (QoS) in dynamic wireless environments.

Keywords: IEEE 802.11 wireless networks, Predictive Handoff, Inter-cell Handoff, Access point, Received signal strength, Mobility management, Data-rate-aware Handoff.

1 | Introduction

The rapid proliferation of wireless communication technologies has transformed the way users access network services across residential, institutional, commercial, and public environments. Among these technologies, Wi-Fi, based primarily on the IEEE 802.11 family of standards, has become a fundamental component of modern wireless connectivity because of its deployment flexibility, relatively low infrastructure cost, broad device support, and progressively increasing Data Rate (DR) [1–3]. Wi-Fi connectivity is now pervasive in homes, offices, airports, hotels, educational institutions, healthcare facilities, and other public environments, where wireless Access Points (APs) provide users with convenient access to the Internet and network services. The ubiquity of wireless interfaces in smartphones, laptops, tablets, embedded systems, and Internet-of-Things (IoT) devices has further increased the importance of IEEE 802.11 Wireless Local Area Networks (WLANs) as an access technology for data-intensive and mobility-dependent applications [2], [4]. A WLAN provides network connectivity through a wireless radio-frequency medium and can complement or, in some environments, substitute for conventional wired local area networks. The IEEE 802.11 standards define the communication mechanisms, medium access procedures, and operational architectures used by WLAN devices [1], [3]. A device participating in an IEEE 802.11 network is generally referred to as a station (STA), which may be stationary or mobile. In infrastructure-based WLANs, mobile stations communicate through an AP that provides wireless access and connectivity to the distribution system. The coverage region associated with an AP constitutes a Basic Service Set (BSS), while multiple interconnected BSSs can form an Extended Service Set (ESS) [1], [3], [5]. Deploying multiple overlapping APs enables WLANs to provide continuous network coverage over relatively large areas and allows mobile users to move between coverage regions while maintaining access to network services [6], [7].

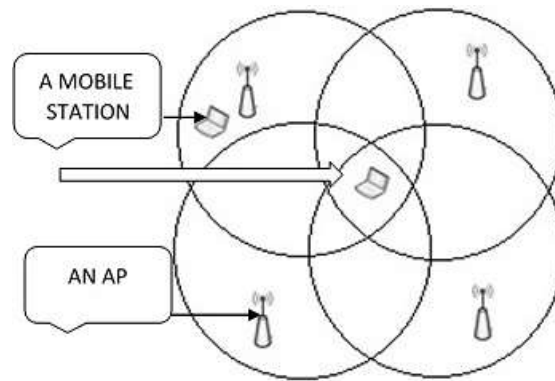


Fig. 1. ESS with multiple BSS.

However, the overlapping nature of WLAN cells introduces a critical mobility-management problem. As a mobile station moves away from its serving AP, wireless link quality may deteriorate, while one or more neighbouring APs may become increasingly suitable for maintaining connectivity. Consequently, the mobile station may need to transfer its association from the current AP to another AP. This process, commonly referred to as inter-cell handoff, is essential for supporting user mobility in multi-cell IEEE 802.11 WLANs [7–9]. A poorly managed handoff can result in packet loss, temporary service interruption, increased signalling overhead, reduced throughput, and degradation of the user's Quality of Service (QoS) [6], [7], [10]. The conventional IEEE 802.11 handoff process generally involves discovering candidate APs, authentication, and reassociation [11]. Among these operations, AP discovery can constitute a substantial component of handoff delay because a mobile station may need to scan available channels to identify suitable neighbouring APs [10–12]. Consequently, considerable research attention has been devoted to reducing scanning time and minimizing the overall handoff latency [10–13]. Although reducing handoff latency is important, low handoff latency alone does not necessarily guarantee satisfactory network performance after the handoff. A handoff decision that is made solely on the basis of Received Signal Strength (RSS) may associate a mobile station with an AP that provides a stronger signal but a lower achievable DR because of channel contention, interference, traffic load, modulation and coding conditions, or limited available resources [6], [14], [15].

This distinction is particularly important in contemporary WLAN environments, where the user's perceived network performance is strongly influenced by the achievable DR rather than SS alone. RSS primarily provides information about the received power of a wireless signal; it does not directly represent the amount of useful data that an AP can deliver to a mobile station. Two neighbouring APs may therefore exhibit similar or substantially different SSs while providing markedly different DRs. An AP with a slightly weaker signal may, under certain network conditions, offer a higher DR because it experiences lower contention, reduced interference, lighter traffic, or more favourable channel conditions [14], [15]. Selecting an AP solely because it has the strongest signal can consequently result in a suboptimal handoff and may cause the mobile station to experience a rapid decline in achievable throughput shortly after reassociation. This limitation has motivated approaches that incorporate achievable throughput and data-rate information into WLAN handoff decisions [15].

The problem becomes more significant in highly dynamic and densely deployed WLAN environments. As users move across overlapping cells, the suitability of candidate APs changes continuously with variations in user location, channel conditions, network load, interference, and traffic demand [6], [14]. A mobile station may therefore enter a region in which several APs are simultaneously reachable, but their ability to sustain a high DR differs significantly. Selecting a target AP without considering its expected post-handoff DR can lead to unnecessary handoffs, ping-pong effects, increased management traffic, and repeated reassociation, consuming wireless resources that could otherwise be used for data transmission [6], [9], [15]. Consequently, an effective handoff mechanism should not only determine when a handoff should occur but should also predict which AP is capable of sustaining an adequate DR after the handoff. Recent research has increasingly explored predictive handoff, machine-learning-based handoff prediction, and intelligent AP selection to anticipate mobility conditions and improve handoff decisions [16–18]. However, the integration of predicted data-rate trends of both serving and neighbouring APs into an inter-cell handoff decision remains an important area for further investigation. This limitation provides the motivation for developing a predictive inter-cell handoff technique for IEEE 802.11 wireless networks that incorporates data-rate information into the handoff decision process.

2 | Literature Review

Recent research has increasingly explored predictive and intelligent approaches to address these limitations. Shao et al. [16], for example, investigated the integration of IEEE 802.11ax and edge computing for seamless handover in industrial WLANs. Their edge computing-based multi-service bearer mechanism employed technologies such as Orthogonal Frequency Division Multiple Access (OFDMA) and Multi-User Multiple-Input Multiple-Output (MU-MIMO) to dynamically allocate resource units according to service requirements. The study also introduced a seamless handover mechanism using virtual AP sentinels to reduce channel scanning delay and an improved particle swarm optimization algorithm for multi-objective handover decisions. These approaches demonstrate the potential of combining intelligent resource management and predictive handover mechanisms to improve WLAN mobility. However, the study also identifies limitations in adapting resource allocation to heterogeneous multi-service requirements, indicating that further attention is required to incorporate service and performance conditions into handover decisions. Predictive intelligence has also been investigated beyond IEEE 802.11 networks. Sulaiman and Al-Raweshidy [17] proposed a reinforcement-learning-based predictive handover mechanism for 5G and beyond networks. Their approach used mobility information and real-time feedback to anticipate handover events and improve handover decision-making compared with conventional and machine-learning-based approaches. The reported results indicate improvements in handover success rate, latency, and disconnection time. Nevertheless, predictive mechanisms based on reinforcement learning can introduce additional requirements for training data, computational resources, scalability, and privacy protection. These considerations are particularly relevant when predictive handoff mechanisms are intended for real-time deployment in resource-constrained or highly dynamic wireless environments. Similarly, Khan et al. [18] examined handover prediction and AP selection in ultra-dense Wi-Fi networks using a machine-learning framework integrated with a Software-Defined

Networking (SDN) controller. Their approach predicted potential handover events and incorporated throughput estimation into AP selection. The study reported reductions in unnecessary handovers compared with RSS- and distance-based approaches and demonstrated improvements in throughput relative to conventional AP selection strategies. These findings provide evidence that incorporating performance-related parameters into handoff decisions can improve WLAN mobility management. However, the reliance on simulation environments and controlled network conditions raises questions concerning the applicability of such approaches to heterogeneous and dynamically changing real-world WLAN deployments. Furthermore, using throughput as an AP-selection parameter does not necessarily address the problem of predicting the future DR available to a mobile station before handoff. The authors in [6] presented a scheme for understanding handoffs in a large IEEE 802.11 wireless network. The research was motivated by the need to monitor wireless networks in order to reveal areas that need attention for better performance. The objective was to identify deficiencies in 802.11 protocol implementations. A vicinity sniffing technique in which a set of wireless devices known as sniffers was deployed to passively monitor packets in a wireless network. Data were collected using the notion of persistence and prevalence for the association of a client to an AP. The scheme provided a trend for SS to detect disconnection and understand when a handoff should occur. However, the research was only empirical without functional implementation to resolve the identified deficiency. In [19], the authors worked on handoff in video sessions between WLANs. The work focused on preserving real-time video streaming sessions during the handoff process in WLANs. Session Proxy (SP) and AP buffer were used to overcome the delay variation and frame loss caused by handoff. Received Signal Strength Intensity (RSSI) and Loss Frame Ratio (LFR) were also used to know the point at which to initiate the handoff. The results showed that frame loss during handoff was prevented. Both SP and AP cache frames for a mobile station are delivered as soon as the association is complete, and the RSSI level is sufficient. This approach showed that the SP brought about higher implementation flexibility. It can serve as a solution for Internet Protocol Television (IPTV) with the delivery of video-on-demand and live transmission. This work cannot support a real time application due to the amount of time required to perform handoff. In [20] research on how a Multichannel Virtual Access Point (MVAP) can be used for seamless handoff in IEEE 802.11 wireless network is presented. This work focuses on the behaviour of mobile station using the concept of Virtual Access Point (VAP) to handle seamless handoff in a multichannel WLAN, where APs can listen to each other on different channels. This VAP-based approach allowed the use of non-overlapping channels to decrease interference and increase overall network capacity. The objective was to develop an MVAP to support seamless handoff in a network with APs operating on multiple channels. The behaviour of an AP was considered by creating a virtual AP responsible to be a mobile station. The mobile station used a VAP to communicate with the AP. Whenever there is a need for handoff, the actual AP serves as an intermediary between the VAP and AP2. Hence, a mobile station appears to be connected always to a VAP. The results showed that MVAP handles the change of AP (handoff) without disrupting the current communication. At the end of the research, an MVAP for seamless and efficient handoff was developed. The work was implemented in a real-life environment using a new version of PACMAP (a tool for packet manipulation and performance evaluation) running on top of the madwifi driver. However, there was an increase in collisions when many clients were active simultaneously, leading to a high overhead cost of handling a VAP for each station, which makes the solution unscalable. In [9], a Fuzzy logic predictive algorithm for wireless LAN fast inter-cell handoff is proposed. The research was motivated by the need to propose a scheme that reduces IEEE 802.11 system handoff time. The objective was to develop a fast handoff scheme based on a Fuzzy Logic Predictive Control that will predict the best AP before handoff. A Fuzzy Logic Predictive Control that computes the Average Signal Intensity (ASI) and the Signal Intensity Variation (SIV), and feeds them to the fuzzy inference engine to obtain an access point aptitude value was developed and validated. The work provides a framework that reduces handoff inter-cell time by 90% thus providing better QoS to VoIP and other real time applications. The effect of management frame was not considered in selecting the input parameters and also inadequate input parameters limits proper selection of the best AP. In [21], the design of an AP-based handoff scheme for IEEE 802.11 WLANs is presented. The research was based on the need to satisfy the handoff requirement for the 4G standard. The specific objective was to establish a handoff scheme

for IEEE 802.11 networks by equipping APs with multiple Wireless Network Interface Cards (WNICs). An implementation of a new handoff protocol, which was designed for multiple WNICs and places the handoff decision in the APs without modifying the hardware of existing stations, was carried out. The scheme fulfils real-time applications with stringent delay requirements. However, consideration was not given to the effect of management frames on the handoff process. The authors in [13] presented a scheme for improving IEEE 802.11 WLAN Handoff Latency by AP-based modification. The objective was to provide a fast handoff solution to support VoIP service and other multimedia traffic without disruption to mobile users. The methodology involved the development of the Multiple Interface Seamless Handoff (MISH) protocol. The protocol ensures that each AP has multiple WNIC working in different channels to notify the mobile users of handoff. This scheme provides a handoff protocol for continuous services without interruption to clients' service but handoff delay duration gradually increases as packet rises.

3 | Methodology

A fuzzy-logic-based predictive controller was developed for an IEEE 802.11 wireless network. It was used for predicting the Optimal AP (OAP) before the handoff process initializes. Signal intensity, relative position of the mobile station to the AP, and DR of the AP were used for selecting the OAP. The use of long-term signal in measuring signal intensity produces better results than instantaneous SS. Hence, the ASI [9] expression was used as follows:

$$ASI(t) = \frac{\sum_{i=1}^n SS_{beacon}(t,i)}{n}, \quad (1)$$

where t is the current time, n is the number of beacon frames received at time t , and $SS_{beacon}(t, i)$ is a function that represents the intensity of the SS received at time " $t-i$ ".

The relative position of the mobile station with respect to the AP determines the distance between the mobile station and the AP. Since signal intensity varies according to proximity to an AP, the difference in signal intensity at various times indicates that a mobile station is moving away or toward the AP. A negative difference means moving away from the AP, while a positive difference indicates moving towards the AP. SIV ascertains that a mobile user is moving towards the AP, and it is obtained as follows:

$$SIV(t) = \frac{ASI(t) - ASI(t-k)}{t - (t-k)}, \quad (2)$$

where $ASI(t)$ is the present signal intensity, $ASI(t-k)$ is the signal intensity k seconds earlier, t represents the present time, and $t-k$ is the earlier time.

The amount of data provided by an AP per second is the DR value of the AP. An AP with the highest signal intensity may not always have the best DR. In case of browsing or utilizing the internet, data usage and DR are imperative parameters [22], and due to the development of various standard protocols for WLAN, it becomes imperative that the DR is taken into consideration during the period of handoff. Today, we have IEEE 802.11a, b, g, n, ac, and ax with defined bandwidths of 54mbps, 11mbps, 54mbps, 600mbps, 1.3gbps, and 4.5gbps. The ability to hand over to the available AP with the highest DR will prevent further handoff and the ping-pong effect. It is of interest to know that DR is always fluctuating due to the effect of many factors such as interference, Signal-to-Noise Ratio (SNR), attenuation (distance), and so on. The thermal noise and the interference power are produced by uncorrelated sources. The cumulative noise is the sum of the power density of the thermal noise and the interference power [14] and is calculated as follows:

$$P_{noise} = P_{int} + P_{white_noise}. \quad (3)$$

The channel throughput is obtained as follows:

$$C = B \ln \left(1 + \frac{P_{signal}}{P_{noise}} \right), \quad (4)$$

where C is the capacity (DR), and B is the bandwidth of the transmission channel.

Fuzzification of the three parameters was performed as follows: ASI and DR use very strong, strong, medium, low, and very low fuzzy sets, while SIV and aptitude use positive, small positive, zero, negative, and small negative as their fuzzy sets. The triangular membership function was used as follows:

$$f(x; a, b, c) = \max\left(\min\left(\frac{x-a}{b-a}, \frac{c-x}{c-b}\right), 0\right), \quad (5)$$

where x is the membership function, a is the start point, b is the peak, and c is the end point of ASI, SIV, and DR respectively.

For defuzzification, the centroid method was employed as follows:

$$Z^* = \frac{\int u\beta(z).zdz}{\int u\beta(z)dz}, \quad (6)$$

where Z is the center of each symmetric membership function computed for each AP. The AP with the highest value of Z gives the OAP and is computed as follows:

$$OAP = \max(\{f(Z): Z = 1, 2, 3, \dots, n\}), \quad (7)$$

where n is the upper bound of APs.

Given that t represents time in seconds, handoff is performed as follows:

$$\forall t = 2s,$$

$$OAP_f = \begin{cases} Z, & \text{if } Z > OAP \\ OAP, & \text{if } Z < OAP \end{cases} \quad (8)$$

where OAP_f is the final OAP used for handoff.

There are 125 rules used for this work. The following are some of the rules:

- I. If ASI is very strong, SIV is positive, and DR is very strong, then OAP is positive.
- II. If ASI is very strong, SIV is positive, and DR is strong, then OAP is positive.
- III. If ASI is very strong, SIV is positive, and DR is medium, then OAP is positive.
- IV. If ASI is very strong, SIV is positive, and DR is low, then OAP is small positive.
- V. If ASI is very strong, SIV is positive, and DR is very low, then OAP is small positive.
- VI. If ASI is very strong, SIV is small positive, and DR is very strong, then OAP is positive.
- VII. If ASI is very strong, SIV is small positive, and DR is strong, then OAP is positive.
- VIII. If ASI is very strong, SIV is small positive, and DR is medium, then OAP is small positive.
- IX. If ASI is very strong, SIV is small positive, and DR is low, then OAP is small positive.
- X. If ASI is very strong, SIV is small positive, and DR is very low, then OAP is zero.
- XI. If ASI is very strong, SIV is zero, and DR is very strong, then OAP is small positive.
- XII. If ASI is very strong, SIV is zero, and DR is strong, then OAP is small positive.
- XIII. If ASI is very strong, SIV is zero, and DR is medium, then OAP is zero.
- XIV. If ASI is very strong, SIV is zero, and DR is low, then OAP is zero.
- XV. If ASI is very strong, SIV is zero, and DR is very low, then OAP is negative.
- XVI. If ASI is very strong, SIV is negative, and DR is very strong, then OAP is small positive.

XVII. If ASI is very strong, SIV is negative, and DR is strong, then OAP is zero.

XVIII. If ASI is very strong, SIV is negative, and DR is medium, then OAP is zero.

XIX. If ASI is very strong, SIV is negative, and DR is low, then OAP is negative.

XX. If ASI is very strong, SIV is negative, and DR is very low, then OAP is negative.

4 | Simulation Experiment

The system was simulated using various blocks on Simulink in the MATLAB environment. The signal builder was used as the source of the wireless signal and noise (interference). The basic wireless parameters needed for handoff (ASI, SIV, and DR) were derived from the signals generated by this block. The signal builder is shown in *Fig. 2*, while the general overview of the system is presented in *Fig. 2*.

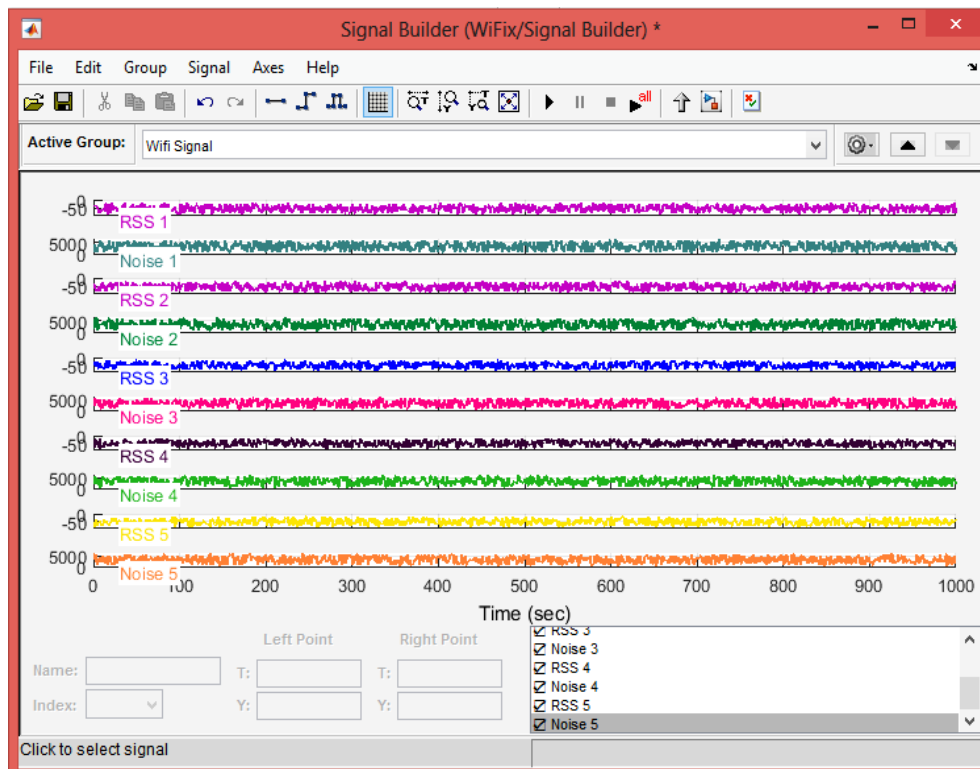


Fig. 2. The signal generated by the signal builder block.

The RSS of an AP lies between -20db and -80db. The signal at -20db is very strong, while at -80db the SS is very weak. Random numbers between these two ranges were generated as the RSS for the system. The same

procedure was repeated for RSS2 to RSS5. Each RSS represents an AP. A pseudorandom value of noise is also generated. A single noise is taken as the sum of the total noise (the white noise) in the AP.

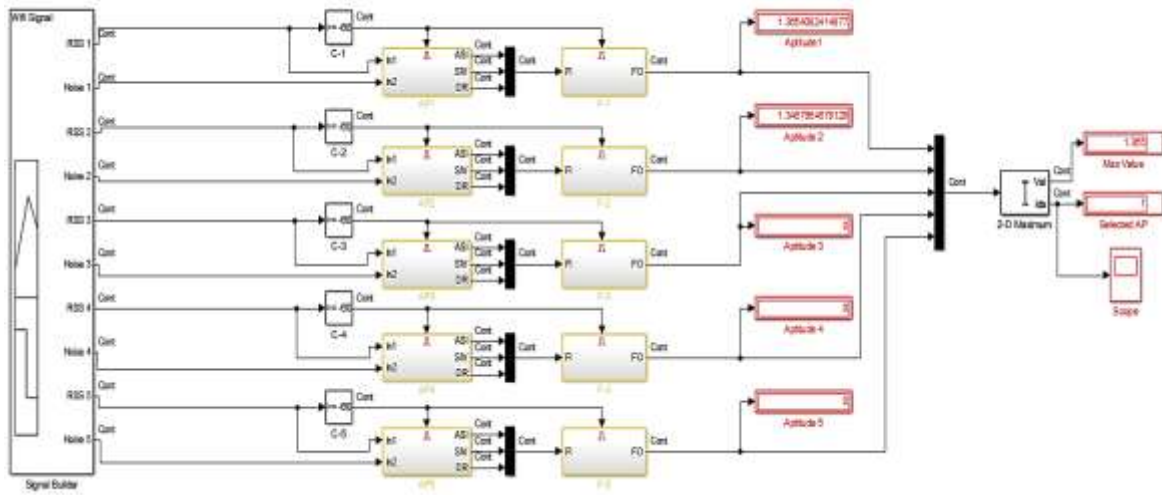


Fig. 3. The general overview of the simulated system.

5 | Computation of Input Parameters

The processor block in Fig. 4 was created for each AP. It has two inputs and three outputs. The inputs are RSS and noise. The outputs are DR, ASI, and SIV. The Average of RSS received over a period of time was used as our ASI. The mean block computes the moving average as ASI. Also, the difference block finds the difference between two successive values of ASI. This difference is the variation in the signal intensity. The difference can be used to determine if a mobile device user is moving closer to an AP or away from it. SIV is the variation or difference between two successive ASIs. The noise level at a point in time was computed from the signal power intensity and the AP bandwidth to generate the DR value.

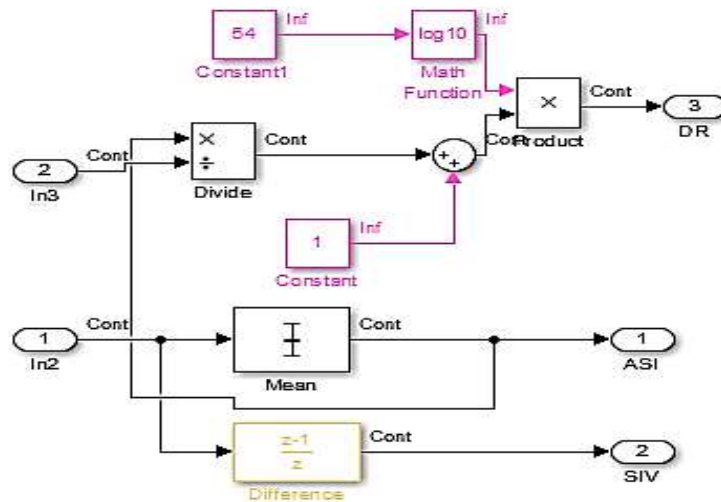


Fig. 4. Processor block.

The controller was developed with the historical data and fuzzy rules.

5.1 | Rule Viewer

The Fuzzy rule viewer was used to view the rule correlation of the various input parameters and the output. It is shown in *Fig. 5*.

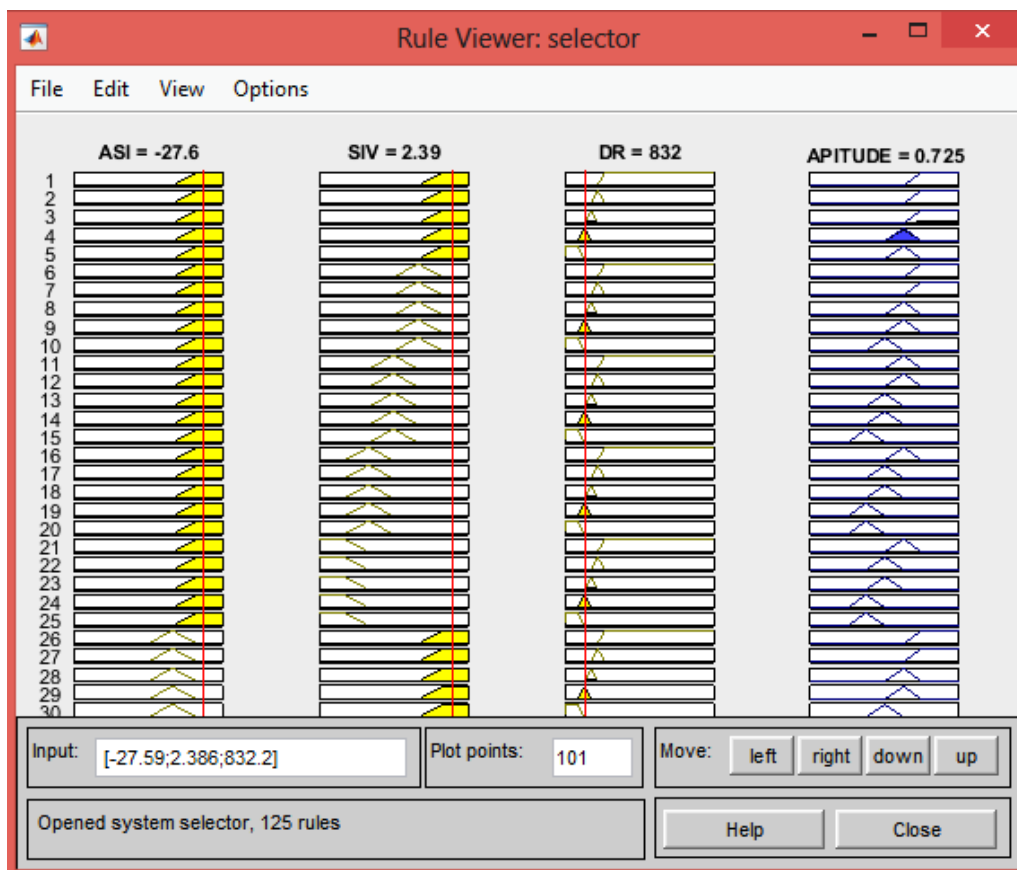


Fig. 5. Fuzzy rules viewer.

The signal intensity changes as the distance between the mobile user and the AP changes. So, the DR also changes if there is a change in the interference or the number of users on the AP. Hence, the OAP is determined every two seconds. The outcome is compared with the previous value of OAP. The AP with the highest aptitude is chosen as the current OAP.

6 | Results And Discussion

The system was tested based on the time taken (in seconds) to move from one point to another around the five (5) APs. A total time of 100seconds and 1000seconds were used for testing and are presented in *Table 1* and *Table 2*.

Table 1. Time series and selected AP using 100seconds.

Time Taken (for 100s)	Selected AP
Starting point (0)	1
0-10	1
10-20	4
20-30	5
30-40	1
40-50	1
50-60	1
60-70	5
70-80	1
80-90	2
90-100	3

The APs selected after a time interval of ten (10) seconds are stated in *Table 1*. Due to the short amount of time before handoff, less time was spent on an AP. The graphical plot showing the scope is shown in *Fig. 6*.

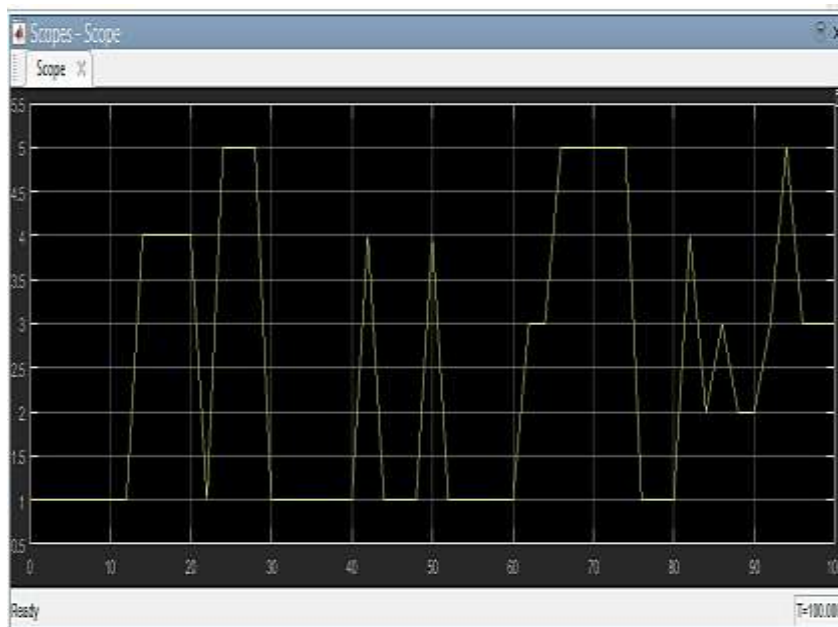


Fig. 6. The plot of the time series against the selected AP with 100secos.

Time Taken (in Seconds)	Selected AP
Starting point (0)	1
0-100	1
100-200	5
200-300	4
300-400	3
400-500	3
500-600	3
600-700	5
700-800	1
800-900	5

Table 2. Time series and

900-1000	1
1000seconds.	

selected APs using

The APs selected at a time interval of one thousand (1000) seconds are stated in *Table 2*. More time was spent on one AP before handoff. An appropriate AP was selected with both short and long time intervals. The graphical plot is shown in *Fig. 7*.

**Fig. 7. The plot of the time series against the selected AP with 1000seconds.**

The comparison of the current research with other existing works is presented in *Table 3* as follows:

Table 3. Comparison of results of current research with the results of existing works.

Systems Considered	Current Work
Raghavendra et al. [6] Used only SS to perform empirical analysis of frames. Handoff was not implemented.	ASI, SIV, and DR are used for actual prediction of the handoff process
Sepúlveda et al. [9] Used only ASI and SIV as input parameters	ASI, SIV, and DR are used as input parameters
Chan and Lin [21] More management frames increase latency	Fewer management frames are possible. Latency is short.
Sanghavi and Bansode [13] Increase in packet-delayed handoff	Fewer management frames override the effect of packets in the handoff process

7 | Conclusion

This study developed a predictive inter-cell handoff technique for IEEE 802.11 WLANs to address the limitations of conventional handoff mechanisms that primarily rely on signal intensity and reactive AP selection. The Fuzzy Predictive Control mechanism uses ASI, SIV, and DR as inputs to a fuzzy inference engine to determine the access point aptitude of candidate APs and predict the OAP before handoff initiation. The findings demonstrate that DR is an important parameter for OAP selection, since the AP with the strongest signal does not necessarily provide the highest achievable DR. By incorporating DR alongside signal intensity and its variation, the proposed technique enables more performance-aware AP selection, reduces unnecessary handoffs and associated management-frame overhead, and helps mitigate potential congestion. Furthermore, by predicting the target AP before handoff, the conventional scanning stage is avoided, resulting in an approximately 90% reduction in inter-cell handoff time and improved QoS. The study therefore demonstrates the potential of data-rate-aware predictive handoff to provide faster and more efficient mobility management in IEEE 802.11 WLANs.

8 | Recommendation

This work is useful for wireless radio manufacturers in designing APs. Network engineers and network administrators should give adequate attention to signal intensity and DR of an AP when planning their network. However, further research can be carried out by performing handoff by more than one node on a single AP at the same time.

Author Contribution

Conceptualization, O. T. F. and S. A. O.; methodology, O. T. F.; formal analysis, O. T. F.; writing-reviewing and editing, S. A. O. and O. K. B.; project management, S. A. O.

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Data Availability

All data supporting the reported findings in this research paper are provided within the manuscript.

Conflict of Interest

The author declares that they do not have any conflict of interest.

Consent for Publication

The author confirms consent for the publication of this work.

Ethics Approval and Consent to Participate

This article does not contain any studies with human participants performed by the author.

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