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METHODOLOGIES AND APPLICATION

Reduction in ping-pong effect in heterogeneous networks using fuzzy logic

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Abstract

Heterogeneous networks enable mobile users to stay connected anytime and from anywhere, providing a platform for multiple radio technologies to cooperate in order to furnish network subscribers with seamless connectivity. Excess number of wireless access points in a heterogeneous network results in exposing the mobile users to a number of networks at a time. The cell boundaries are critical where the quality of service may suffer. These boundaries share signal reception from multiple cells, and this causes mobile terminals to connect back and forth between multiple cells. This is known as the ping-pong effect that leads to a greater number of call drops. This work presents a fuzzy handover decision system that uses mobile user traversal history to mitigate the ping-pong effect. The proposed parameter is fed into fuzzy decision system to quantify the decision parameters. The technique increased the value of handover success metric, compared to Monte Carlo method from 0.3 to 0.6.

Keywords Ping-pong effect · Heterogeneous networks · Vertical handovers · Fuzzy system

1 Introduction

Next generation of wireless communication is expected to provide an improved communication infrastructure, in terms of services, data rates, quality and mobility. Heterogeneous networks are considered to play a key role in various real-time applications. Ubiquitous mobility is possible using handover mechanisms that are efficient in terms of call drop rate and latency. Handover is one of the significant rising issues as the deployments of modern wireless technologies such as macrocell, femtocell and WLANs have made it difficult for the mobile terminals (user end devices) to decide that which access network in their coverage area will serve them the best. The handover process determines the best anticipated access network and accordingly decides whether to carry out a handover or not (Wei et al. 2011; Rahman et al. 2017).

The end users in these days demand for seamless communication link whether they are idle, walking or riding on the vehicles. This calls for a need to have a handover mechanism that can take account of varied user movements while changing the link from one access point to another. Moreover, in such scenarios the movements of mobile terminal and subsequently the number of expected handovers increase to a great extent. The increased number of handovers leads to problem of ping-pong effect (PPE). The PPE is caused by unnecessary or incorrect decisions and leads to a greater call drop rate which can cause serious degradation in the QoS for heterogeneous network (HetNet) users (Ait Mansour et al. 2018; Long et al. 2017).

It is a challenging job for handover algorithms to operate in the real time and make precise decisions in extremely dynamic environment. Fuzzy logic is widely used to make decisions when the available information is incomplete or imprecise. Numerous applications of fuzzy logic have been used by researchers including multi-criteria decision-making problems (Fahmi et al. 2017), improvement in energy efficiency in heterogeneous networks (Vasudeva et al. 2017)

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and performing handovers in LTE-A networks (Saeed et al. 2017).

This paper proposes a fuzzy-based decision system for reduction in ping-pong effect in heterogeneous network handover. The proposed system uses traversal frequency of familiar paths. The track of traversal history increases the predictability of correct destination access network and consequently decreases the call drop rate in heterogeneous networks. The rest of paper is organized as follows. Section 2 provides review on existing techniques used for ping-pong effect mitigation. Section 3 presents the methodology for design of fuzzy system. It also introduces and explains the prediction-based parameter and its detailed working. Section 4 presents the analysis and results. Finally, conclusions are drawn in Sect. 5.

2 Literature review

In the heterogeneous network environments, an effective handover process is often required to ensure seamless connectivity. Various researchers have attempted to provide efficient handover algorithms to reduce the ping-pong effect and to provide seamless connectivity to end users. The handover techniques can be broadly classified as threshold-, timing- and intelligence-based techniques. The general drawbacks of timing-based techniques are that either the holding times of connection are too long or an increase in the probability of call drop is observed. The threshold-based methods perform decision based on RSS parameters but do not address other factors of uncertainty that may lead to the ping-pong effect. Moreover, the intelligence-based techniques have been proposed including game theoretic approaches, artificial neural networks, fuzzy logic and hybrid systems that have attempted to reduce the ping-pong effect. Related work on the ping-pong mitigation is summarized in Table 1.

Threshold is usually used as basic criteria to cap any variable that is used a decision parameter. In typical traditional RSS-based ping-pong reduction schemes, the mobile terminals compare the real-time RSS with a threshold value and compare it for performing handover. Additionally, the weightage-based methods involve assignment of different weights to decision parameters. Entropy matrix method is one of the examples of such techniques which assign different weight to input parameters and decide a decision of handover based on this.

Various researchers have used timing-based methods to perform handovers and mitigate PPE in the adjacent base stations. Time can be variably used, in different ways to perform the handovers. For instance, the difference in arrival times of frames may be used to detect user's motion. Moreover, a commonly known parameter, time to trigger is able to give the calculation about the instant at which handover may be initiated. The time interval can be incorporated if PPE is detected prior to handover. The time delay will then delay the handover until user has already passed through the uncertainty zone. It is challenging for network selection algorithms to operate in real time and make precise decisions in the presence of large-scale and small-scale fading encountered in mobile environment.

The fuzzy logic (FL) approach can be used as a solution, since it can deal with imprecise or difficult to obtain data. FL provides a way to make decisions based on real-time scenarios when the information available is not complete. In a FL design, input parameters are passed through a fuzzifier and then fed in their fuzzy inference engine, where set of fuzzy rules is applied to obtain fuzzy decision sets (Saeed et al. 2017; Kim et al. 2007; David et al. 2012; Ghanem et al. 2012; Yiheng et al. 2012; Çalhan and Çeken 2013; Sharma and Khola 2012; Tsai et al. 2016; Aibinu et al. 2017).

3 Methodology

A unified approach is required for vertical handovers in HetNets so that all disparate wireless technologies may integrate together to provide end users with the best possible QoS and QoE. The task of designing a generic model, which is applicable to HetNets for future cellular infrastructure, includes a number of processes including the information exchange between entities, i.e., defining the protocol, designing suitable decision engine and so on Barolli et al. (2008). Thus, a wide literature survey was performed to review most suitable message exchange and existing vertical handover (VHO) models. The cellular communication is developing rapidly, and new technologies keep making place for them. In recent years, WiFi, WiMaX, LTE, GSM and many more technologies have been deployed. However, all the technologies use small or macrocells to deploy their network. Cooperation-based networks are foreseen as solution of network integrations, where all these cells will collaborate with each other to provide seamless service to end mobile users. Thus, a system that may be used to provide handover platform for cooperating technologies is presented. Figure 1 shows the steps involved in developing the fuzzy inference system for VHOs in heterogeneous cellular networks.

3.1 Input design and simulation of fuzzy logic system

A typical fuzzy logic system has three main entities involved, i.e., the inputs, output and the fuzzy inference system. The fuzzy inference system contains the rules for tuning algorithm or pattern recognition algorithm for the fuzzy logic system. The rules are designed to adapt with an algorithm based on the existing data. There are two kinds of fuzzy

Table 1 Summary of related works on ping-pong mitigation

Type of mitigation technique	Title	Year	Technique	Discussion
Threshold-based technique	Ping-pong avoidance algorithm for vertical handover in wireless overlay networks	Kim et al. (2007)	Use two thresholds for handoff	Do not consider RSS fluctuation and heterogeneous parameters
Timing-based technique	Theoretic analysis of handover failure and ping-pong rates for heterogeneous networks	David et al. (2012)	They conclude that time to trigger should ideally be both cell specific and user equipment specific	Do not incorporate shadowing or fast fading in the model
Timing-based technique	Reducing ping-pong handover effects in intra-E-EUTRA networks	Ghanem et al. (2012)	Timer is set in a first step to select whether the handover is ping-pong or general, if ping-pong HO is detected, then in the next step they delay the handover completion and keep the old path	High timer values can lead to dropped calls. Also keeping old path may reduce system capacity
Timing-based technique	Semi-active handover algorithm assisted on location for heterogeneous wireless networks	Yiheng et al. (2012)	Algorithm presented is based on the location for WiFi and cellular networks. They estimate the speed and direction of MT using least square fit model; BS predicts the time in which MS stays in WiFi	High timer values can lead to dropped calls. Only applicable for WiFi and take long processing time
Timing-based technique	Artificial neural network-based vertical handoff algorithm for reducing handoff latency	Çalhan and Çeken (2013)	A three-layer neural network approach is used and five neural networks for separate technologies including WiFi, GSM, GPRS, UMTS and WiMAX are constructed	The method has outperformed over most of the traditional handoff decision methods used in terms of handoff latency and selection of the best network
Intelligence-based technique	Fuzzy logic-based handover decision system	Sharma and Khola (2012)	The received signal strength is predicted using the LMS and use fuzzy logic to calculate HO factor	The system decides HO decision on the basis of RSS, BW & user preference. Ping-pong (PP) reduction has not been well addressed
Intelligence-based technique	Using fuzzy logic to reduce ping-pong handover effects in LTE networks	Tsai et al. (2016)	Fuzzy logic-based decision policy is used to mitigate ping-pong effect	The ping-pong effect is suppressed but the technique requires improvements by considering other handover parameters
Intelligence-based technique	Novel type-2 fuzzy logic technique for handover problems in a heterogeneous network	Saeed et al. (2017)	Handover optimization algorithms for LTE-A networks	The two-input fuzzy system has achieved optimal cell load balance and improved handover efficiency
Intelligence-based technique	Development of hybrid artificial intelligence-based handover decision algorithm	Aibinu et al. (2017)	Hybrid artificial neural network-based RSS prediction to reduce ping-pong effect	Use of artificial neural networks to predict RSS does not provide efficient transition times

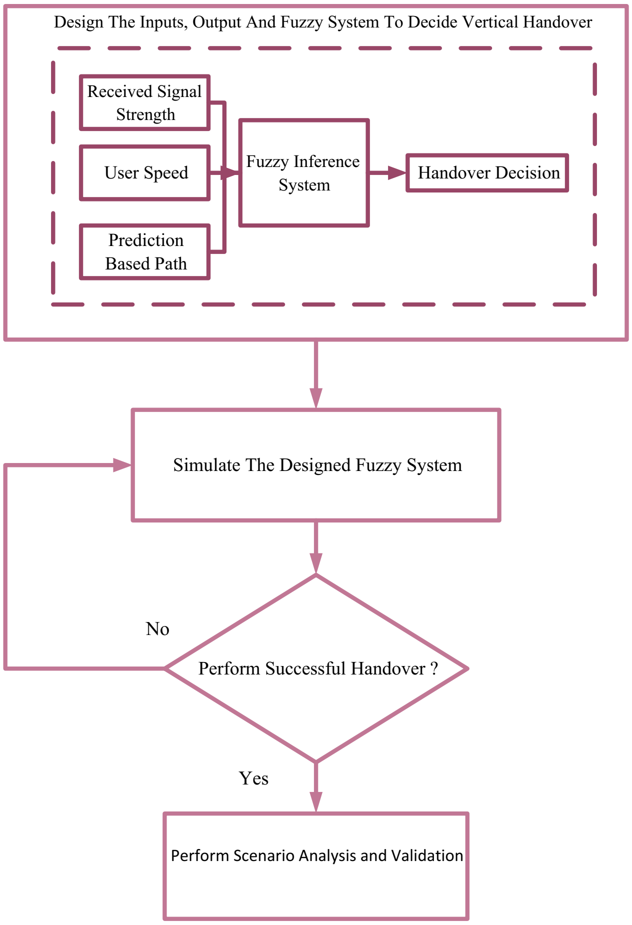


Fig. 1 Development of the VHO Framework

inference systems, namely Mamdani type and Sugeno type. A Sugeno-type fuzzy rule is based on only constant values, whereas Mamdani-type fuzzy system is based on outputs mapped as functions. A Sugeno inference is used for vertical handovers in Fortes et al. (2015), whereas Mamdani approach is applied in Fortes et al. (2015) to perform handovers. Recent studies have shown fuzzy logic as a useful tool in the design of intelligent systems including controlling of a mobile robot, information granule information, airplane flight control and reduction in ping-pong effect in vertical handovers (Tsai et al. 2016; Castillo and Melin 2008; Sanchez et al. 2015a, b; Cervantes and Castillo 2015; Castillo et al. 2016). In this research, both fuzzy models are explained and simulated in order to find out the more suitable inference system for vertical handover application. The models are used inside Intelligent-Media Independent Handover, using Fuzzy Logic Toolbox in MATLAB to evaluate the handover decision in the proposed intelligent generic handover framework. In this work, firstly the performance of VHO is investigated using two commonly used inputs (RSS and user speed). Subsequently, the investigation is done again after involving the prediction of path existence as a third input parameter. The two systems are then compared to analyze the effect of adding path prediction parameter for VHO. The aim of this research is to investigate whether the proposed parameter will influence the handover decision. The above-mentioned parameters are explained briefly in succeeding sections.

3.1.1 Received signal strength (RSS)

The input to the fuzzy inference engine is obtained from RSS stream generated using MATLAB. The range of RSS is -130 to 40 dBm. The gaussmf function is used as the membership function, and the RSS fuzzy sets defined are: Unacceptable (≤ -81 dBm), Acceptable (range of -81 to -64 dBm) and Excellent (≥ -64 dBm) (Juniper Networks 2011; Patel et al. 2010; Ayyappan and Dananjayan 2008). The RSS here is only the RSS from current cell where the mobile terminal is connected. Figure 2 shows the modeling of RSS input.

3.1.2 User speed

The user speed is an important parameter to be considered while a user is mobile between heterogeneous cells. The user speed has a range of 2–550 Km/h. The membership function used is trimf and is categorized into three different classes with following parameters: pedestrian speed (2–10 Km/h), normal car speed (70–120 Km/h) and high speed (120–550 Km/h) (Luan et al. 2012; Emmelmann 2005). Figure 3 shows the modeling of user speed input parameter.

3.1.3 Prediction-based path

This section presents a path prediction parameter derived from history-based communication graph technique in which previously traversed paths of a mobile terminal are retained, and frequent paths are used to predict mobile terminal movements. This parameter is inspired by intelligent search engine algorithms that identify the commonly used attributes for smart searching. Some of examples of such mechanism are the web search engines such as google, yahoo and bling. When user places a query for the commonly used word, it will automatically appear in the drop down menu of search list. This is done by capturing the frequency of word that a user has searched in the previous browsing history (Minnie and Srinivasan 2011). In this work, the frequency of user path chosen is used in a similar way to predict the track of mobile users. The frequent paths are obtained using daily life movement patterns of mobile users. The daily routine life of mobile subscribers allows mobile terminals to move through the paths according to their routine, which are quite certain to a degree. The users' during normal routine have fixed routes from their home to the work place, to the grocery stores,

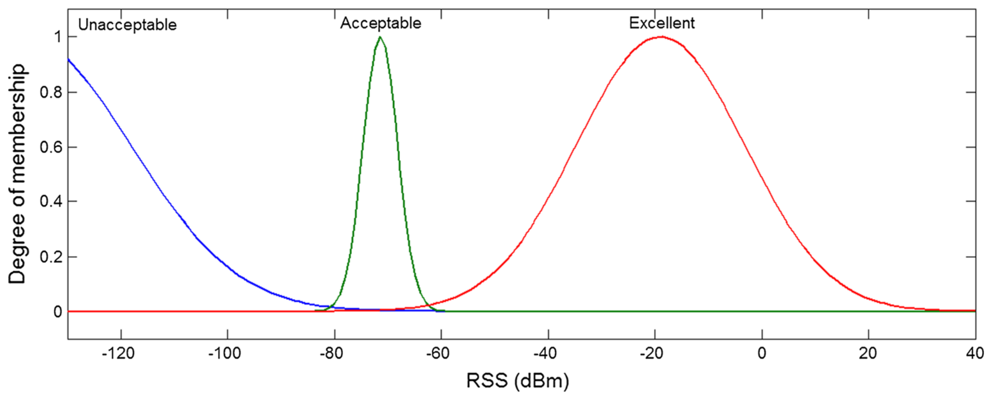


Fig. 2 RSS parameters

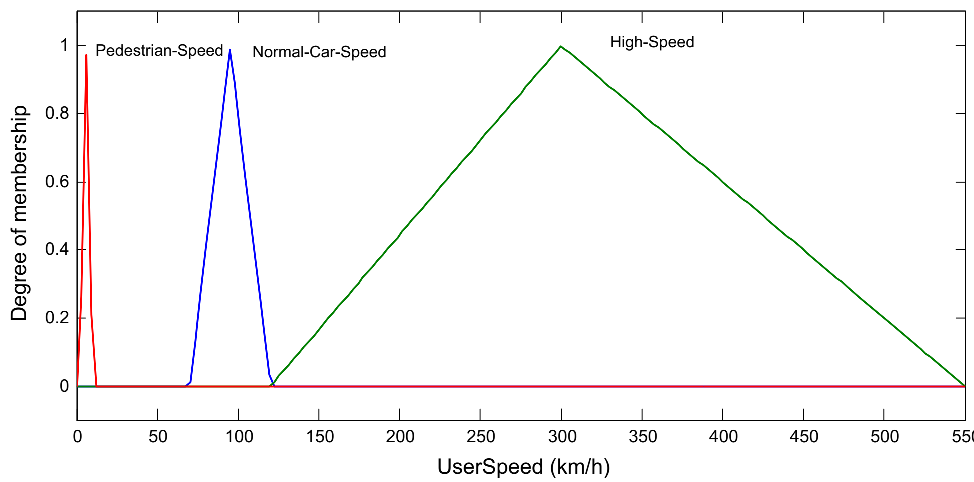


Fig. 3 User speed parameters

health centers and even towards the accommodation places of their close friends or relatives. The regularity of users going through such routes is captured using graph theory, and exploiting this fact, the PPE is mitigated by predicting correct user path, consequently predicting correct destination cell for mobile subscribers.

3.1.3.1 History-Based Communication Graph Users of wireless mobile communications require smooth connectivity while at rest or mobile. The user motion is known to be highly unpredictable, while a user is mobile between heterogeneous nodes. However, there are some actions that are quite certain for every user to perform. For example, the people in working class would probably use the same route to reach to their offices/workplaces at least for five days a week. People who go for sports as a regular activity will mostly use same route to reach their gymnasium or sports centers. Moreover, people going to buy their groceries mostly prefer going to same stores each day, week or month.

In all the above cases, the number of nodes that a user will pass through will become quite certain. This makes a place for history-based approach to perform a VHO and reduce PPE during the handover. Thus, we propose a history-based communication graph technique (HBCGT) to compare previous route (path) that a mobile user has passed through in past window time, denoted as tw, which may be, for example, three days, one week, etc. These paths are then recorded in the pool named as IPS. The paths are calculated using graph theory as explained in next section.

3.1.3.2 Graph Terminology We interpret the handover problem as a communication graph. Given a weighted graph $G = (V, E)$, where V is the set of vertices (wireless nodes) here the nodes refer to fixed heterogeneous base stations/access points, and E is the set of weighted edges (communication links) (Meghanathan 2012). The overlay network is a macro-cellular network and these nodes are underlaid. The example of node 1 is a WiFi node, whereas node 2 may be a residential application node. The two nodes are under laid within a GSM base station.
The following variables are defined:

Vertices, $V = \{0, 1, 2, \ldots H\}$
Edges, $E = \{0, 1, 2 \ldots Y\}$
Weight of each edge, $W_E = [W0, W1, \ldots WY]$

The handover success metric (η) is calculated as:

$$\eta = \text{number of successful handovers / total handovers.} \quad (1)$$

In Eq. (1), η is the ratio which describes the proportion of successful handovers compared to total number of handovers performed in each scenario.

The handover problem is to determine the frequent path between any two heterogeneous nodes, identified as heterogeneous source nodes (HSN) and heterogeneous destination nodes (HDN) in the communication graph. We use assignment of unique weights to the edges. When a handover is triggered to a node, n, a graph is created for each possible path Pi to be developed using weights of each link, up to the current link, i, then, a comparison is made between all Pi, and the frequent paths retained in the IPS according to the accumulative weightage. The path weights are assigned as link probabilities so that the total link weightage subsists in the range between 0 and 1 (Sporns 2003). The weight of unique paths formed after each traversal is calculated as the sum of links involved in the respective route. The sum is denoted by Pwi and can be calculated using Eq. (2)

$$\text{Pwi} = (\text{WL} + \text{WL} - 1 + \ldots \text{Wi}). \quad (2)$$

3.1.3.3 Proposed Ping-Pong Mitigation Technique First of all, the Pwi is obtained for all possible paths. If at a given time, the Pwi becomes equal to any frequently traversed path, which is retained in the intelligent path space IPS(x), where x denotes any path in the pool at which the Pwi value equates to the IPS(x). Then, the handover is performed at the path that gives same cumulative path weightage with any of path in the IPS(x). In such handover case, it is assumed that RSS at destination cell has a value greater than or equal to acceptable RSS at the cell edges. The heterogeneous network model under consideration consists of microcell, femtocell and macrocell. Since the coverage zone under consideration is the overlapping/interference area of these cells, thus the RSS at the cell edge zones for each cell must be considered. The acceptable RSS of microcell ranges from − 82 to − 65 dBm (David et al. 2012), the typical RSS range of macrocell is − 95 to − 77 dBm (Ayyappan and Dananjayan 2008), and the RSS from femtocell to microcell at cell edges ranges from − 95 to − 62 dBm (Patel et al. 2010). Allowing for the above-mentioned RSS, the acceptable value at cell edges is taken to be within the range of − 81 to − 64 dBm.

However, if the current path does not match any value in the pool, then the path is interpreted as a completely new route. The new route is updated in the IPS using dynamic update. If the route is interpreted as a new route for the first traversal, then there is a need for the criterion to perform handover to the target node. Therefore, in such an event, the handover is made based on conventional strategy which is based on RSS (Mach and Becvar 2014). The worst case scenario could happen when the user history is not available, and the RSS of any candidate destination cell is below the certain threshold; nevertheless, the basic parameter for handover is RSS comparison because if RSS is not up to the certain minimum level, then connection cannot be sustained; handover criteria may include other parameters (Çalhan and Çeken 2013), but the basic requirement of minimum required RSS has to be maintained.

Here, the conventional strategy refers to the simple comparison of RSS from the serving node to the target node to decide a handover (Mach and Becvar 2014). In the RSS-based VHO, if the target node RSS is greater than the serving node, this indicates user movement in the closer vicinity of new node; thus, handover is performed, but if the RSS of target node is less than serving node, it means that the user is not in the vicinity of target cell and does require a handover. The major steps involved in the proposed scheme are presented next.

Compute Pwi for all possible paths
If
Pwi = IPS(x) where x is any path inside IPS pool
Then
Perform handover to target HDN that gives same Pwi
Else if
RSS of Target Node > RSS of Serving Node
Then
Perform Handover to Target Node
Else if
RSS of Target Node< RSS of Serving Node
Then
No Handover Required

3.1.3.4 A working example Assume an example where the user's mobile equipment is familiar with five paths traversed regularly by the user. The pool of path IPS(x) includes the paths matrix such as: [home-work, work-gym, home-gym, home-grocery store, home-children's school].

Now mapping the above matrix to numerical values and assigning value to the retained paths in the IPS, suppose IPS(x) = [0.55, 0.9, 0.98, 0.7, 0.8]. Each of the IPS values corresponds to a familiar user path that has been traversed previously.

Consider a path A where the user passes through four edges, $E = \{0, 1, 2, 3\}$. Let $W_0 = 0.1$, $W_1 = 0.2$, $W_2 = 0.3$ and $W_3 = 0.35$. The Pw1 will be calculated as Pwi = [0.1 + 0.2 + 0.3 + 0.35], i.e., Pw1 = 0.95. The IPS does not have a value of 0.95, which means that the route is new for the user; thus, handover will be performed based on the RSS criteria.

A second example is taken, again considering path B; we assume the user takes straight L-shaped path to reach to the same destination node. The user in this case has to traverse through five edges with different weights, let

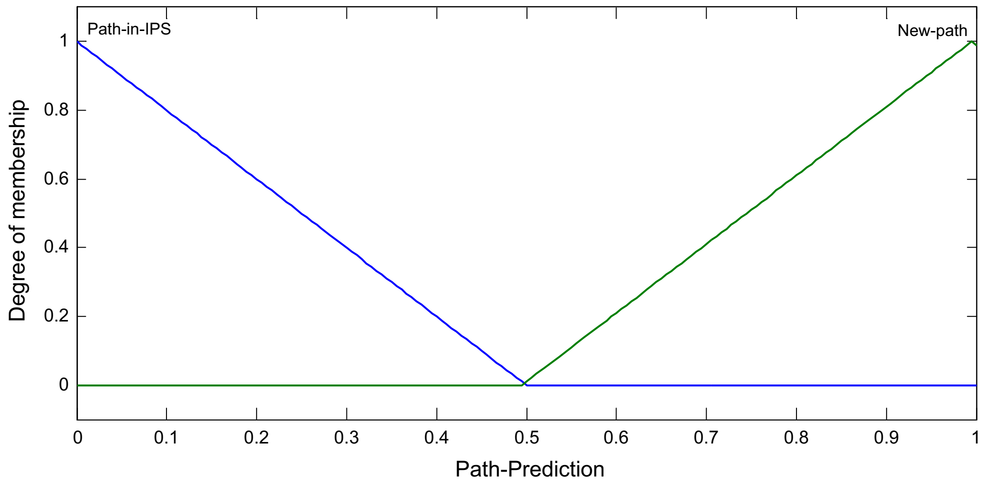


Fig. 4 Prediction-based path parameters

$W_0 = 0.21, W_1 = 0.02, W_2 = 0.17, W_3 = 0.35$ and $W_4 = 0.05$. We obtain Pw2 = [0.21 + 0.02 + 0.17 + 0.35 + 0.05], i.e., Pw2 = 0.8. Referring to IPS(x) = [0.55, 0.9, 0.98, 0.7, 0.8], the fifth value, i.e., IPS (5), equals to Pw2; thus, this path is considered as a familiar path and chosen by the mobile terminal. Therefore, the handover is decided to be favorable where the user path is familiar. The proposed prediction-based path parameter serves to reduce the uncertainty in random users' movements. A vertical handover framework utilizing proposed prediction-based path parameter can thus be designed for improved handover performance.

The theory of fuzzy logic reflects the uncertainty of the objective things and the uncertainty of humans exploring the new objects. Therefore, fuzzy logic is applied using the prediction-based path parameter (Singhrova and Prakash 2009). Assuming the set of IPS over a coverage area, for any x ∈ IPS, we can get a number with prediction-based path ∈ [0, 1] to decide whether the path ∈ IPS. We have the mapping as follows: If prediction-based path ∈ [0, 0.5], the path ∈ IPS and if path ∈ [0.5, 1], the path is considered to be a new path.

To evaluate the proposed scheme, the users are moved through different paths using the proposed history-based scheme, having same path space but various possible routes. For the same movement, the mobile terminals are led to perform handovers using RSS criteria. The successful numbers of handovers for both cases are presented in "Results" section.

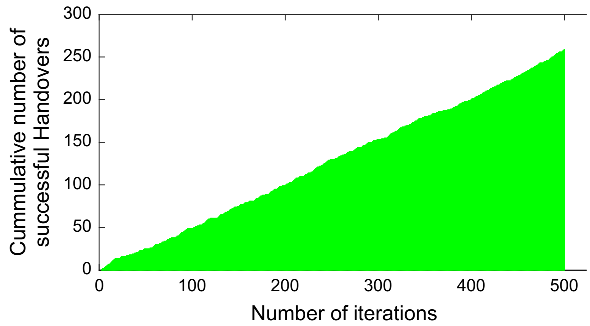
3.1.3.5 Prediction-based path input in fuzzy system This parameter allows path prediction for mobile terminal using the paths that have been previously traversed. The membership function chosen is trimf in the range of 0 to 1. Two membership functions have been used to categorize the path predicted from user history, i.e., (< 0.5) for retained (predicted) path and (≥ 0.5) for new path, respectively. A value of prediction-based parameter less than 0.5 means that the path is predicted to be inside intelligent path space (IPS). This path is known to be user familiar path, and user will be directed to handover to the cell in this direction. Else, the path is considered to be unfamiliar or new path, this is depicted by value ≥ 0.5, and the rules will restrict the handover in this case. History-based path is an enhancement to the previous works where only RSS (David et al. 2012) is taken into account for performing handover decisions. The history-based path concept can be studied in detail in Naeem et al. (2014). The user motion is known to be very random. However, there are some actions that are fairly definite for every user to perform. For instance, the people in working class would probably use the same route to reach to their offices/workplaces at least for five days a week. People who go for sports as a regular activity will typically use same route to reach their sports centers. Moreover, people going to buy their groceries mostly also prefer going to same stores. Thus, in all the above cases, the number of nodes that a user navigates through becomes quite certain. This makes the history-based prediction approach suitable to perform a VHO in HetNet environment. Figure 4 shows the prediction-based path input parameters.

4 Results and discussion

This section presents the results and findings of the research. The initial results on validation of the prediction-based path are presented first. Following that, analysis and results of the fuzzy logic system have been provided.

4.1 Evaluation of successful handovers using prediction-based path

We assume a fixed RSS of − 80 dBm at the source node for simplification purposes. At destination node, random varying



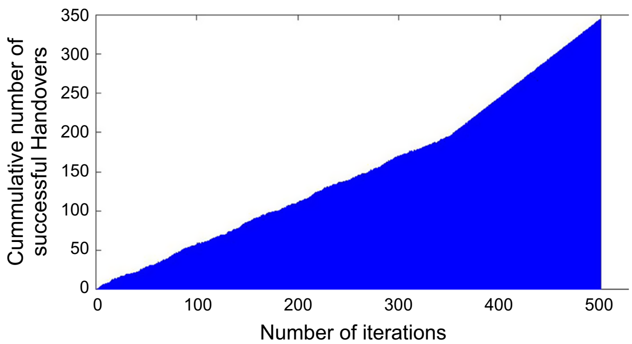


Fig. 5 Handovers performed for 500 iterations using **a** RSS and **b** HBCGT

RSS values in the range of − 80 and − 95 dBm are used. Number of nodes to create each path in the IPS pool is 5, i.e., $V = [1, 2, 3, 4, 5]$, which is fixed for each experiment; however, the values of Pwi varied according to link weights. Correspondingly, the number of edges is 4, i.e., $E = [1, 2, 3, 4]$.

Simulations carried out for 20 iterations were applicable to comparatively heavily loaded cells where the greater number of mobile terminals was involved in the study. Compared to the simulation using 10 iterations, where handover success metric has increased to 0.9, using proposed scheme, for 20 iterations, it has increased to 0.85. This can be justified as a result of greater number of load inside the cell cluster, however, compared to RSS scheme (Çalhan and Çeken 2013); it is observed that the handover success has significantly increased. The technique is further investigated by increasing the experiment up to 500 iterations. The cumulative successful handovers for 500 iterations using RSS and HBCGT are shown in Fig. 5.

A comparison for the yielded value of handover success metric for each iteration including 10, 20, 100, 200, 200, 400 and 500 iterations is made to obtain steady-state results, as depicted in Table 2 and Fig. 6.

The results illustrated that considering the previous routes taken by mobile users can reduce the ping-pong handovers, and have a significant impact on the reduction in rejected calls and thus on successful handovers.

Table 2 Comparison of increased iterations for RSS scheme and proposed HBCGT

Iterations	10	20	100	200	300	400	500
Metric for RSS	0.7	0.5	0.52	0.55	0.57	0.59	0.51
Metric for proposed HBCGT technique	0.9	0.85	0.67	0.69	0.68	0.68	0.69

The results illustrate that the steady-state comparison of RSS-based traditional handover technique with the proposed HBCGT yields 0.56 success metric on average for RSS technique while 0.74 success metric for the proposed technique. Further validation of proposed technique is done by comparing the proposed technique to timer-based technique (Çalhan and Çeken 2013). Figure 7 shows the comparison between the performance of proposed technique and timer-based technique in terms of dropped calls rate.

The dropped calls have been analyzed for timer values of 0.5, 1, 5, and 10 as presented in Çalhan and Çeken (2013). The average call drop rate for timer-based technique is observed as 0.0175 for the HBCGT, whereas for timer-based technique it is found as 0.0575. Thus, the dropped call average rate is observed to be much lesser than the timer-based technique. The proposed technique has outperformed both when compared to traditional RSS-based handover technique or timer-based ping-pong reduction technique.

In addition, the user motion among the heterogeneous nodes is quite unpredictable, which makes handover decisions rather complex. Thus, FL-based handover decision framework is developed to ease the execution of handover decisions in order to rationalize the deficient knowledge about handover parameters. Proposed framework predicts the user motion by taking advantage of previous paths traversed by a mobile terminal. Simulation results demonstrate that the designed decision engine is efficient for performing VHOs considering three selected parameters, i.e., RSS, user speed and path prediction.

4.2 Fuzzy vertical handover inference system

The use of HetNets capitalizes overlapping coverage and allows user devices to take advantage of being best connected to multiple networks. The fuzzy inference system uses rules to map the inputs to the output. In this system, seven rules have been defined for two-input fuzzy system as given in Table 3. The scenario is applicable for a moving terminal from small cells and macrocells.

Considering a two-input fuzzy system, the handover is performed based on the category of RSS and user speed. If the RSS reception of current point of attachment is not

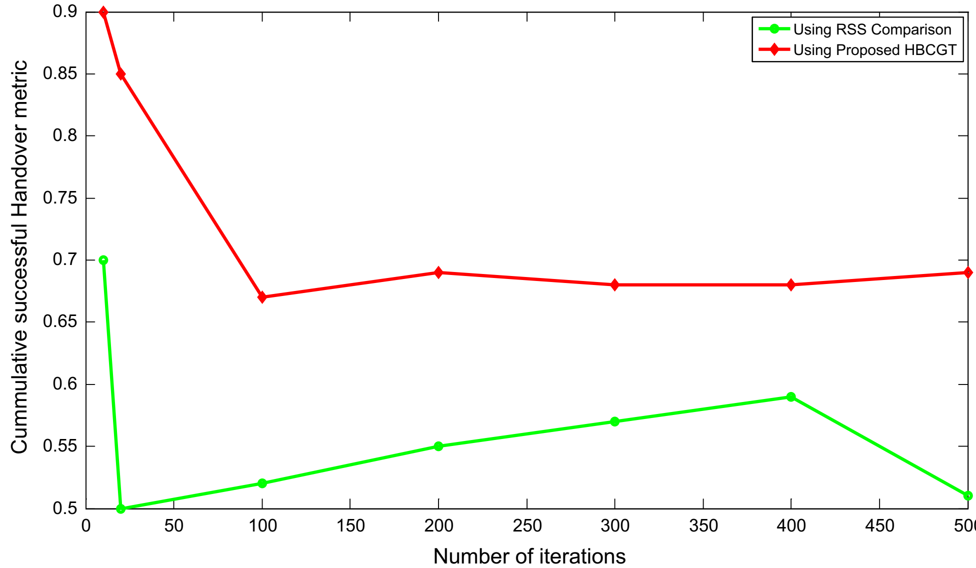


Fig. 6 Handover success comparison of RSS versus proposed technique up to steady state

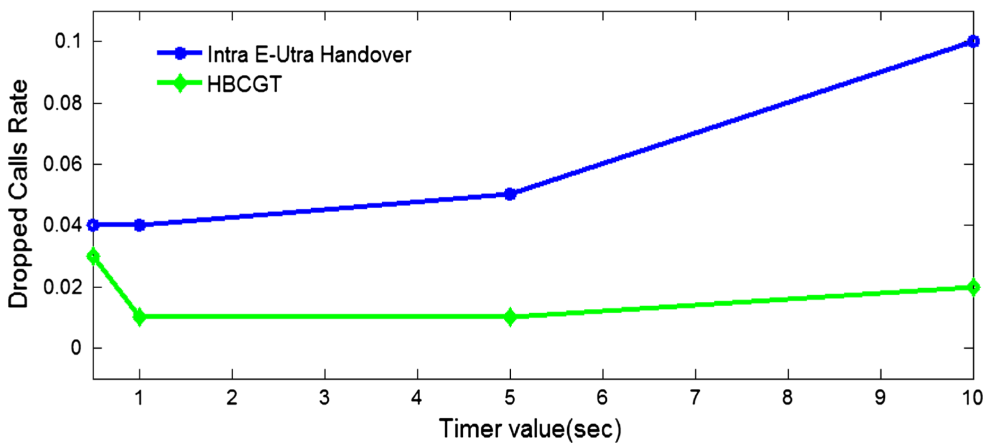


Fig. 7 Dropped calls rate of timer-based technique versus proposed technique

Table 3 Rules for two-input fuzzy system

Rules	RSS	User speed	Handover decision
1	Unacceptable	–	Handover
2	Acceptable	Pedestrian	No handover
3	Acceptable	Normal car speed	Handover
4	Acceptable	High speed	Handover
5	Excellent	Pedestrian	No handover
6	Excellent	Normal car speed	Handover
7	Excellent	High speed	Handover

acceptable, it follows that the terminal must handover to the base station with higher RSS; thus, a handover decision is made regardless of user speed (rule 1). If the user is at the pedestrian speed, and RSS is acceptable or greater (rule 2 and rule 5), then no handover is made, because the user may be present near same location for a greater amount of time, and if the user moves to unacceptable RSS zone, then rule 1 will apply again. However, for the normal car speed, handover will be performed for both acceptable and excellent RSS (rules 3 and 6), because the terminal will move from the overlapping area within short span of time, and if handover is not performed, then call may be dropped. Similarly, for high speed too, an instant handover is required before mobile terminal moved out of current point of attachment; thus, a handover decision is made (rules 4 and 7). There are 13 rules for three-input fuzzy system. Table 4 depicts the rules for three-input system.

Different rules are applicable for fuzzy engines of two-input and three-input systems. The fuzzy engine using three parameters must consider all three parameters while making decision, since the decisions are dependent on each parame-

Table 4 Rules for three-input fuzzy system

Rules	RSS	User speed	History-based path	Handover decision
1	Unacceptable	–	–	Handover
2	Acceptable	Pedestrian	Path in IPS	Handover
3	Acceptable	Pedestrian	New	No handover
4	Acceptable	Normal car speed	Path in IPS	Handover
5	Acceptable	Normal car speed	New	No handover
6	Acceptable	High speed	New	No handover
7	Acceptable	High speed	Path in IPS	Handover
8	Excellent	Pedestrian	Path in IPS	Handover
9	Excellent	Pedestrian	New	No handover
10	Excellent	Normal car speed	New	No handover
11	Excellent	Normal car speed	Path in IPS	Handover
12	Excellent	High speed	Path in IPS	Handover
13	Excellent	High speed	New	No handover

ter. The RSS is a basic parameter to retain a certain minimum QoS; thus, if the RSS is not acceptable, handover to the cell with acceptable RSS has to be performed, regardless of user speed or user's previously used paths (rule 1). Moreover, for acceptable and excellent RSS, if the user path is already saved in the IPS pool, then handover is made to the target cell that the mobile terminal's history confirms for all categories of user speed, i.e., whether the user is at pedestrian, normal car or high speed (rule 2, rule 4, rule 7, rule 8, rule 11 and rule 12). For any new paths that have not been traversed by the users before, the handover is not performed (rule 3, rule 5, rule 6, rule 9 and rule 10), unless unacceptable RSS is experienced by the user and for this case, rule 1 applied again. The 13 rules used in fuzzy inference system are based on these rules.

The output to the fuzzy inference engine is modeled as the handover decision. The handover decision is made using threshold value as an output. The threshold in Mamdani-based fuzzy system is modeled as trimf function. The threshold less than 0.5 means that a decision of no handover has been made, and threshold greater than or equal to 0.5 means performing handover is decided. However, since the Sugeno fuzzy design allows us to deal with constant numbers, the Sugeno-based fuzzy system is modeled as two constant values, where a '1' means handover and any lower value is rounded off to '0' deciding no handover.

The proposed FL VHO framework offers self-adaptive handover. To compare the handover behavior using three different parameters, simulation is performed with and without the newly introduced history-based path prediction parameter. The fuzzy inference system is simulated for both Mamdani type and Sugeno type. The prior gives the output as a fuzzy set, whereas subsequent gives the result as a constant. This work has evaluated both Mamdani and Sugeno fuzzy engines to analyze most appropriate system for the best handover decision.

Figure 8 demonstrates three-dimensional interpretation of Mamdani FL system to investigate the change in the handover threshold with respect to two parameters, User speed and RSS. The handover threshold varies only as a result of user speed and the signal strength, as defined in the rules for fuzzy engine using two parameters.

Figure 9 shows three-dimensional Sugeno system output to investigate the change in the handover threshold with respect to two parameters, as for prior Mamdani system.

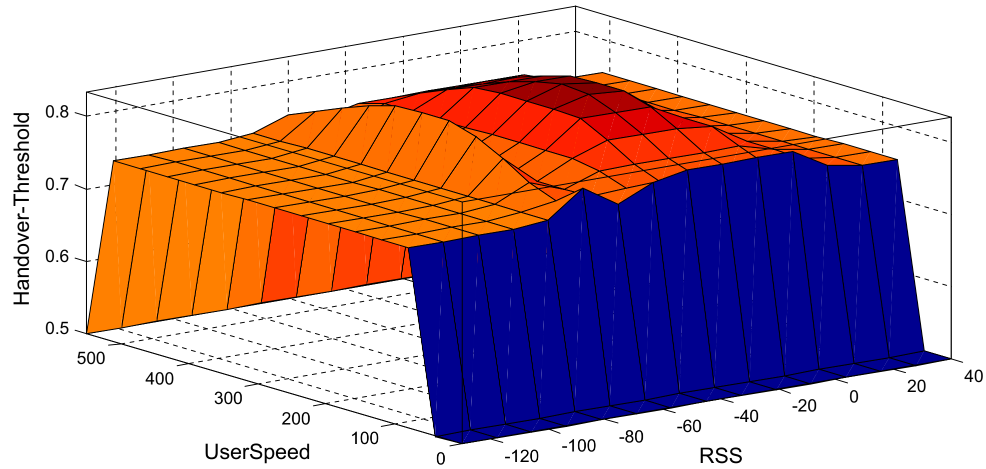
For the two-input systems, the handover threshold exceeds 0.5 not only when RSS low, but also randomly during the simulations for both Mamdani type and Sugeno type. However, the decision to 'handover' may be quantified clearly for Sugeno fuzzy system, since it enables to map the output to constant values, i.e., 0 or 1, unlike Mamdani where output is represented using functions.

Figure 10 depicts three-dimensional view of Mamdani system output as a result of using path prediction input. The system follows the rules as defined in the system however, the graph falls constantly according to defined thresholds, and for some cases, it is observed to drop below threshold, i.e., 0.5, performing wrong decisions and leading to call drop.

Figure 11 depicts the three-dimensional vision of Sugeno system output using three-input parameters, inclusive of path prediction. As the path is predicted during simulation (i.e., value < 0.5), the handover decisions to perform correct handover become vibrant for Sugeno-based system. Thus, the Sugeno model has outperformed decision compared to Mamdani model for VHO application.

The path prediction input is added to the fuzzy systems to evaluate the handover decision. It is observed that the handover threshold is clearly high for unacceptable RSS values where prediction-based parameters are involved in the sim-

Fig. 8 Mamdani-2input user speed versus RSS



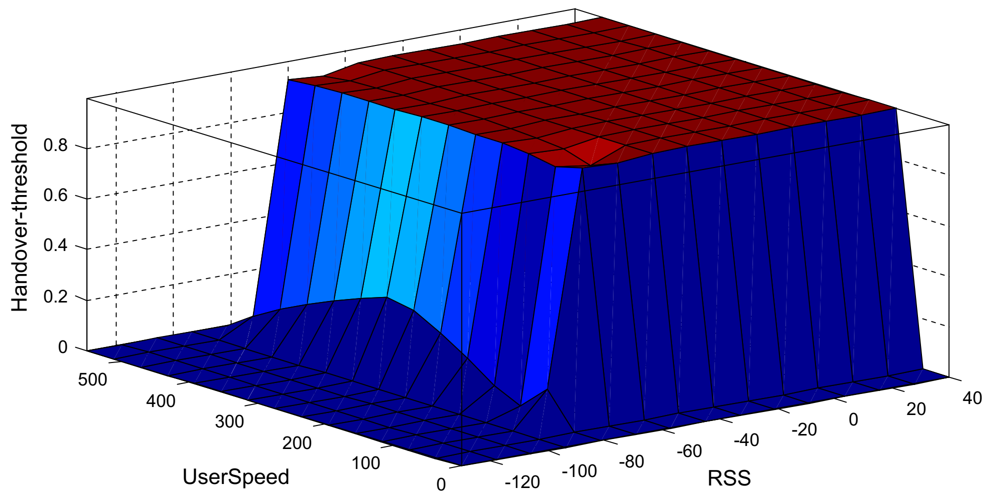


Fig. 9 Sugeno-2input user speed versus RSS

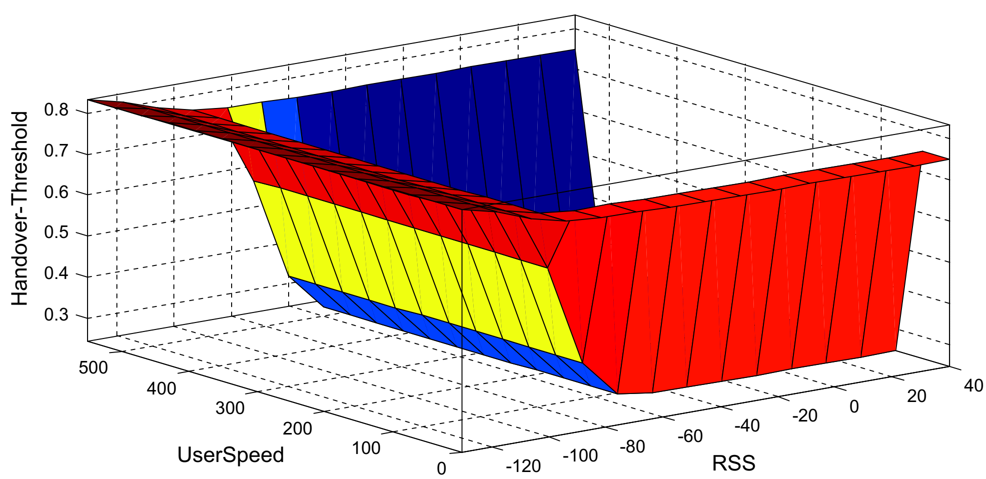


Fig. 10 Mamdani-3input user speed versus RSS

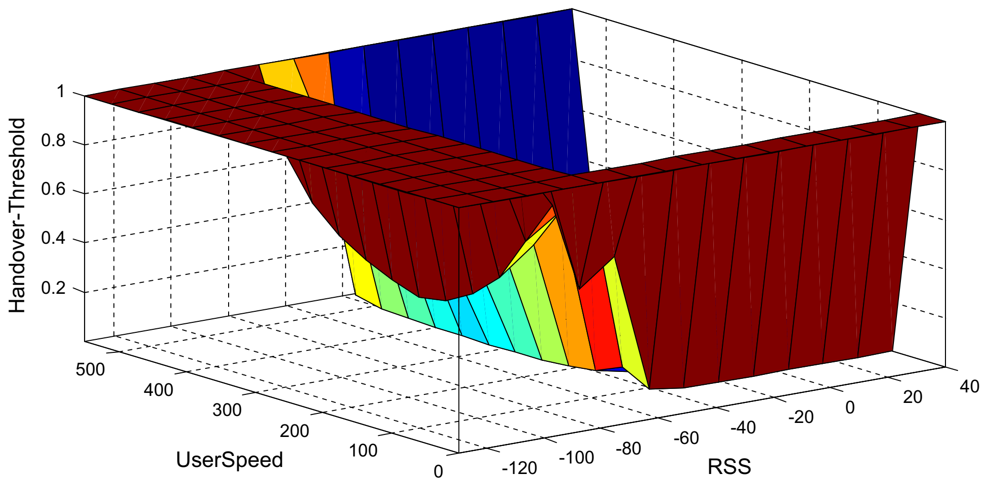


Fig. 11 Sugeno-3input user speed versus RSS

Table 5 Sugeno type with two parameters (RSS, user speed)

Case study	Inputs		Output		
	RSS (dBm)	User speed (Km/h)	Handover value	Handover decision	Expected decision
1	Unacceptable (– 81)	275 (High speed)	0.39	No handover	Handover
2	Acceptable (– 50)	120 (High/normal)	0	No handover	Handover
3	Acceptable (– 50)	7 (Pedestrian)	0	No handover	No handover
4	Excellent (– 64)	7 (Pedestrian)	0	No handover	No handover

ulation. This result is in-line with the theory because the mobile terminal must perform handover, when RSS goes below acceptable threshold (Luan et al. 2012).

Moreover, for the three-input systems, the prediction-based parameter has allowed a greater number of successful handovers for both the systems. The impact of acceptable and excellent RSS is same for varying parameters. In addition, the handover threshold retains high value until the RSS reaches the acceptable value. Thus, the handover threshold decides performing a handover regardless of the fact that path is predicted or the speed of the mobile terminal has changed. As the RSS is increased to the acceptable value, and following that to the excellent value, the handover decision is decided based on the rules for user speed and previously traversed path. If RSS is above the acceptable range and handover trigger is made to a path retained in the IPS pool, then handover is made, and handover threshold is set to high; however, if the path is new, then the handover is not performed unless required by QoS necessity based on RSS. Next section validates the results using few scenarios.

4.3 Scenario analysis and validation

This section implements the proposed system in four case studies and shows different results for each case study. In order to explain the case studies, four scenarios have been designed which use varying RSS, user speed and path prediction, to investigate the impact of introducing path prediction parameter into the study. The validation is conducted by comparing existing work with the Monte Carlo method.

4.3.1 Scenario analysis

The results obtained for each fuzzy engine for four case studies are demonstrated in Tables 5, 6, 7 and 8 and explained afterward. Since RSS is the basic parameter, and no compromise can be taken on unacceptable RSS, the case studies begin with the impact of RSS. The speed and path prediction variations are then examined in these scenarios.

Tables 5 and 6 show expected decisions for Sugeno-type and Mamdani-type fuzzy systems, respectively, for varying RSS values. The path prediction parameter has not been incorporated in these two case studies.

A miss-match in decision for performed and expected handover is shown for case study 1 and 2 in Table 5. This illustrates the wrong decisions have been made in cases of both acceptable and unacceptable RSS for different speeds.

Tables 7 and 8 show the case studies for Sugeno-type and Mamdani-type fuzzy systems, respectively, where the path prediction parameter is involved in the system.

Table 6 Mamdani type with two parameters (RSS, user speed)

Case study	Inputs		Output		
	RSS (dBm)	User speed (Km/h)	Handover value	Handover decision	Expected decision
1	Unacceptable (– 81)	275 (High speed)	0.755	Handover	Handover
2	Acceptable (– 50)	120 (High/normal)	0.5	Handover	Handover
3	Acceptable (– 50)	7 (Pedestrian)	0.231	No handover	No handover
4	Excellent (– 64)	7 (Pedestrian)	0.246	No handover	No handover

Table 7 Sugeno type with three parameters (RSS, user speed and path prediction)

Case study	Inputs			Output		
	RSS (dBm)	User speed (Km/h)	Path prediction	Handover value	Handover decision	Expected decision
1	Unacceptable (– 81)	275 (High speed)	0.3 (path in IPS)	1	Handover	Handover
2	Unacceptable (– 81)	275 (High speed)	0.3 (path in IPS)	1	Handover	Handover
3	Acceptable (– 50)	7 (Pedestrian)	0.6 (new path)	0	No handover	No Handover
4	Acceptable (– 50)	7 (Pedestrian)	0.2 (path in IPS)	1	Handover	Handover

Table 8 Mamdani type with three parameters (RSS, user speed and path prediction)

Case study	Inputs			Output		
	RSS (dBm)	User speed (Km/h)	Path prediction	Handover value	Handover decision	Expected decision
1	Unacceptable (– 81)	275 (High speed)	0.3 (path in IPS)	0.755	Handover	Handover
2	Acceptable (– 50)	120 (High/normal)	0.3 (path in IPS)	0.75	Handover	Handover
3	Acceptable (– 50)	7 (Pedestrian)	0.6 (new path)	0.231	No handover	No Handover
4	Acceptable (– 50)	7 (Pedestrian)	0.2 (path in IPS)	0.75	Handover	Handover

The four scenarios are chosen with changing parameters to investigate the effect of VHO decision on moving users' cases.

In scenario 1, a mobile terminal with a user at pedestrian speed suffers unacceptable RSS reception. In such an event, the handover threshold becomes high and handover to the network with acceptable RSS will be performed.

A mobile user traversing through a previously retained path at normal car speed is considered in scenario 2. The RSS reception is acceptable; in such a case, the output obtained will be a high value. Since fuzzy system recognizes the path as user's frequent path, the user will make a handover to the target path without confusing with other available networks.

In scenario 3, a mobile terminal with pedestrian speed is considered, which goes through a new path and the RSS from current cell is acceptable. In such an occasion, the handover threshold obtained will be low and no handover will be performed.

Finally, in scenario 4, a mobile terminal with excellent RSS is going at pedestrian speed; this scenario is modeled for only two-parameter models. In this case, no handover is experienced. For three-parameter models, acceptable RSS is considered, with pedestrian speed and the path is predicted to be in IPS. Hence, a handover will be implemented.

The case studies show that for both types of fuzzy systems, the fuzzy engine with prediction-based parameter performed better. However, the Mamdani fuzzy system is recommended as more suitable for vertical handovers because the handover in scenarios 1 and 2 for the Sugeno type with two parameters performed unexpected decisions as given in Table 5. This is because the path prediction parameter is not used in two-input system. However, considering the path prediction, if the path is used often, it means that the mobile terminal must execute handover. A wrong decision of no handover here may lead to PPE and call drop (Naeem et al. 2014). The authors of Singhrova and Prakash (2009) state that the number of hand-offs in RSS-based scheme should be greater than multi-parameter-based VHO decisions. As we observe from the data set, using appropriate data, the number of handovers using RSS and user speed-based handover is lesser, compared to the case when additional parameter of path prediction is added to the fuzzy system. Thus, it follows that using proposed three parameters for handover decision, a greater number of successful handovers may be achieved.

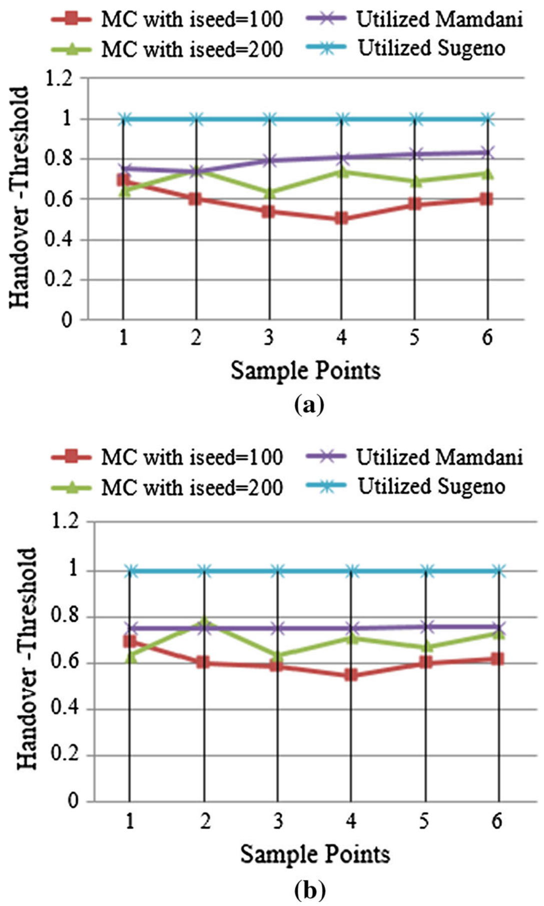


Fig. 12 Handover thresholds at speed of **a** 0 Km/h and **b** 10 Km/h

4.3.2 Validation

The results are compared with the Monte Carlo method used in Barolli et al. (2008), in terms of successful handovers. The authors of Barolli et al. (2008) mentioned that handover in small cell systems is more crucial, since the handover rate tends to be inversely proportional to the cell size for a given user speed. They perform VHO using FL and avoid PPE in the handover decision. However, they do not consider the impact of high speed in making decision of handovers. In this experiment, the sample points are taken for the two speeds used by MC method, i.e., 0 Km/h and 10 Km/h, as shown in Fig. 12a, b), respectively. The handover threshold is clearly high in the proposed Mamdani and Sugeno fuzzy-based system, whereas handover thresholds for MC with iseed = 100 and iseed = 200 remain lower. The lower thresholds imply that successful handover will not be made and thus compared to the MC method; the proposed system has improved the successful handover rate.

In terms of the handover success metric, the values for MC with iseed = 100, MC with iseed = 200, utilized Mamdani and Sugeno are calculated to be $\eta = 0$, $\eta = 0.3$, $\eta = 0.6$ and $\eta = 0.6$, respectively. Figure 13 shows

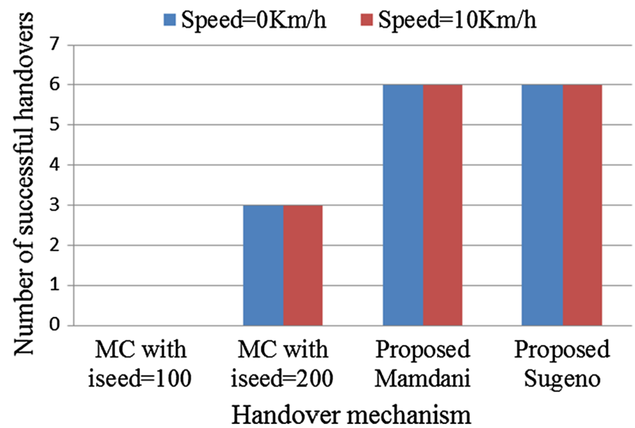


Fig. 13 Number of successful handovers using different techniques

the successful handovers in proposed system for heterogeneous cells are greater compared to MC method used in Barolli et al. (2008).

5 Conclusion

The ping-pong effect occurs at the regions where the cell boundaries overlap and mobile users are prone to multiple receptions. As a result of these receptions, the mobile terminal tries to connect to the cell with higher signal reception. Since the user motion and signal reception both are random, this may lead the mobile terminal to perform incorrect or unsuccessful handovers. In this paper, a fuzzy system is designed to reduce the ping-pong effect in the heterogeneous wireless networks. HBCGT is proposed for prediction of the user path (correct destination access point). The results depict reduction in the average call drop rate compared to timer-based technique. The steady-state system comparison of traditional RSS-based handover technique with the proposed HBCGT yields 0.56 average success metric for RSS-based ping-pong mitigation while an increased 0.74 success metric for the proposed technique is obtained. The handover procedure uses fuzzy logic to quantify the different handover parameters required to perform decisions. The fuzzy logic system uses three inputs, which are: RSS, user's speed and user's prediction path to decide the target cell, which is obtained as the output of fuzzy system named handover decision. This study has demonstrated involvement of frequently traversed path in the fuzzy system has improved the handover success metric from 0.3 to 0.6 as compared to Monte Carlo method. The work can be extended in future by the application of other artificial intelligence methods with the involvement of prediction parameters.

Compliance with ethical standards

Conflict of interest The authors declare they have no conflict of interests

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