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ORIGINAL RESEARCH

Algorithm for vertical handover in cellular networks using fuzzy logic

Siddharth Goutam[1] · **Srija Unnikrishnan**[2]

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Abstract The research paper aims to design and implement an algorithm for vertical handover in cellular networks. The algorithm is based on Fuzzy Logic and the main parameters considered are Received Signal Strength, Channel Capacity, Velocity of the User and distance from Base Station. We have studied the variation in the points of handover under the conditions of variation in the operating frequency of base stations.

Keywords Vertical handover (VHO) · Cellular networks · Vertical handover decision algorithm (VHDA) · Received signal strength (RSS) · Channel capacity · Fuzzy logic · Base stations (BSs) · Universe of discourse · Network load

1 Introduction

The presence of co-existing heterogeneous cellular networks necessitates an efficient handover algorithm in order to provide maximum advantage to mobile users [1]. The handover algorithm should essentially ensure that Quality of Service (QoS) is maintained and does not get deteriorated [2]. Additional consideration of propagation characteristics helps in designing an efficient and effective handover decision algorithm [3–5].

The paper has been organized as follows: Sect. 2 provides the literature survey. Section 3 captures mathematical background. Section 4 gives the design and implementation part. Section 5 gives the simulation results. Section 6 captures analysis of results followed by conclusion and future scope in Sects. 7 and 8 respectively.

2 Literature survey

In this research paper, we have considered the critical parameters for vertical handover in cellular networks. Through literature survey, we have studied and analyzed the path loss and made the improvisations on the models given by earlier researchers. The path loss prediction models can be categorized into three categories (i) empirical (ii) theoretical and (iii) site specific models [6]. The path loss is an important parameter in determining the coverage area of base stations, deciding optimal transmit powers and defining cell boundaries. The propagation model largely impacts signal attenuation and path loss. In turn, path loss governs the Received Signal Strength (RSS), the most crucial parameter that affects the quality of reception and points of handover [7]. The VHDA proposed by Sharma et al. considers predicted RSS and current RSS as input parameters. Prediction of RSS can be improved if path loss calculations are accurate [8]. Precise estimation of RSS also reduces the probability of false handover [3, 9, 10]. The threshold RSS for handoff and acceptable signal to noise ratio (SNR) are prominent factors in calculating the channel capacity [11]. In the research paper by Yaw et al. RSS and bandwidth have been considered as

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✉ Siddharth Goutam
siddharthagoutam@gmail.com

Srija Unnikrishnan
srija@frcrce.ac.in

[1] Research Scholar, Electronics Engineering, Fr. Conceicao Rodrigues College of Engineering, Agnel Technical Education Complex, Fr. Agnel Ashram, Bandstand, Bandra (West), Mumbai, Maharashtra, India 400050

[2] Fr. Conceicao Rodrigues College of Engineering, Agnel Technical Education Complex, Fr. Agnel Ashram, Bandstand, Bandra (West), Mumbai, Maharashtra, India 400050

input to the Fuzzy Inference System (FIS). In [12], the same authors have added QoS as an additional input parameter to the VHDA. The research paper by Yan et al. [13], gives a comprehensive survey of VHDAs. It is a review paper and captures a representative set of algorithms for VHO. The research paper by Barja et al. [14], gives an overview of VHO algorithms and protocols. The paper presents the implementation of a VHDA which ensures efficient communication in Vehicular Network environment. Lahby [15] has presented VHDA which is based on graph theory. The problem is modeled using K partite graph and selection of the best path is made by using cost function and Dijkstra's algorithm. In the research paper by Radhika et al. [16], VHDA is presented which is based on graph theory and analytical hierarchy process (AHP). Also the prominent attributes are identified by using Principal Component Analysis. In the two research papers by Gerla et al. [17, 18], VHDA based on score function is presented. The main parameters considered as inputs to the VHDA are link capacity, cost and battery status. A Universal Seamless Handoff Architecture model is presented and evaluation of the same is done using the test bed. Research papers by Singh et al. [19], presents VHDA based on RSS and bandwidth while research paper by Attaullah et al. [20], presents VHDA based on signal strength, bandwidth, network load and jitter. The research paper by Shen et al. [21], captures multi criteria decision making algorithm which is primarily based on QoS. VHDA between 3 WLANs and UMTS is presented. In the research paper by Liao et al. [22], VHDA based on power level, cost and bandwidth is presented. The paper by Drissi et al. [23], captures multi attribute decision making strategies for the network selection. The comparison of three methods Simple Additive Weighting (SAW), Multiplicative Exponential Weighting (MEW) and Technique for Order Preference by similarity to an ideal solution (TOPSIS) is presented in the research paper.

3 Mathematical background

The challenges in the planning of cellular networks can be resolved, to a certain extent, by evaluating the coverage area and the handover points dynamically, under varying propagation conditions. Figure 1 captures the scenario with two base stations BS_1 (3G) and BS_2 (4G).

The operating frequency of 3G base station is 900 MHz and the operating frequency of 4G base station is 1800 MHz. Figure 2 captures the geometrical analysis of the movement of user. As shown in Fig. 1, the base station BS_1 is positioned at point A and base station BS_2 is positioned at point B. In this paper, the user trajectory is considered to be along straight line AB i.e. the user is moving from point A to point B in a straight line. Figure 2 captures the coverage areas and the user trajectory along line AB.

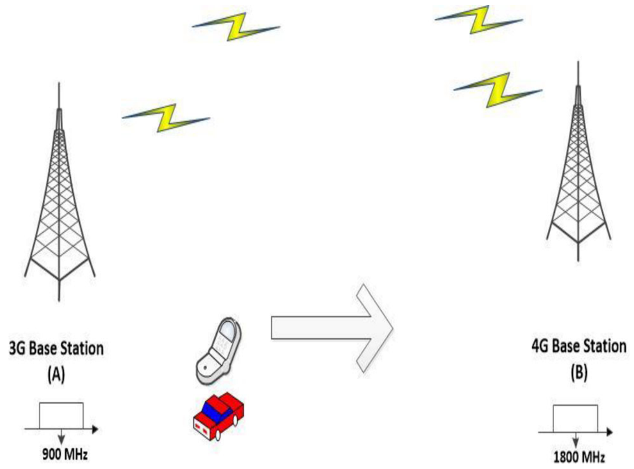

Fig. 1 User trajectory and coverage area

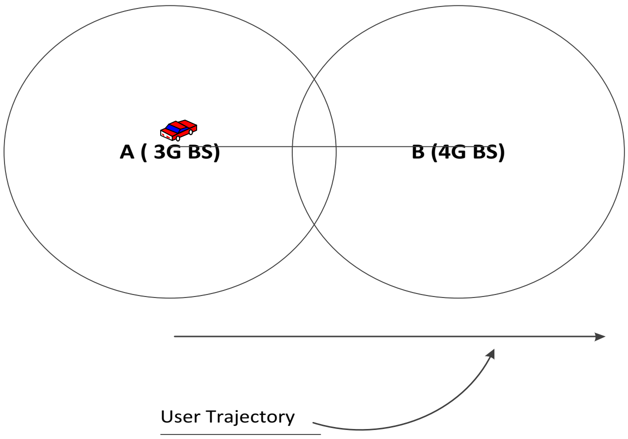

Fig. 2 Geometrical analysis of user trajectory

From Fig. 2, we analyze the user trajectory as follows:

The received signal strength (RSS) and path loss, calculated as per the free space propagation model, is given below

$$P_r = \frac{P_t * \lambda^2}{(4\pi d)^2} \tag{1}$$

where.

P_r – Received signal power (also known as RSS).

P_t – Transmitted power (in watts).

λ—Operating wavelength.

d – Distance from the transmitting sources (in mtrs).

Path-loss is given by

$$\begin{aligned} PL &= TransmittedPower(P_t) \\ &\quad - ReceivedPower(P_r) PL(indB) \\ &= 20\log_{10} d + 20\log_{10} f + 92.5 \end{aligned} \tag{2}$$

where f denotes the operating frequency [2, 6, 7, 24].

The Channel capacity is described by the following equation

$$C = B\log_2(1 + SNR) \tag{3}$$

where

C – Channel capacity & B—bandwidth.

SNR denotes signal to noise ratio.

Considering the thermal noise (white noise) as the significant factor for Noise, we have

$$N_0 = kT \tag{4}$$

where N_0 (in W/Hz) denotes the amount thermal noise which is observed in a bandwidth = 1 Hz.

k denotes Boltzmann's constant, ($1.38 * 10^{-23}$ J/K).

T denotes absolute temperature (in K) [11].

Fuzzy Logic is the approximation theory commonly used to solve problems with uncertainty. The block diagram for Fuzzy Inference System (FIS) is captured in Fig. 3 [2, 25, 26].

As shown in Fig. 3, inputs are converted into fuzzified. FIS consists of membership function, Rule based logic and decision making block. The output is fed into defuzzifier and crisp output is obtained.

The following equation describes the triangular membership function for three variables [2, 25, 26]

$$\mu(x : r, s, t) = \begin{cases} 0, x \le r \\ \dfrac{(x-r)}{(s-r)}, r \le x \le s \\ \dfrac{(t-x)}{(t-s)}, s \le x \le t \\ 0, x \ge t \end{cases} \tag{5}$$

Figure 4 describes the triangular membership function as described in Eq. 5 [2, 25, 26].

Figure 5 captures the phases of the handover. As shown in Fig. 5, the process of handover starts with information gathering phase, providing inputs to FIS, performing the comparative analysis and then finally executing the handover [10].

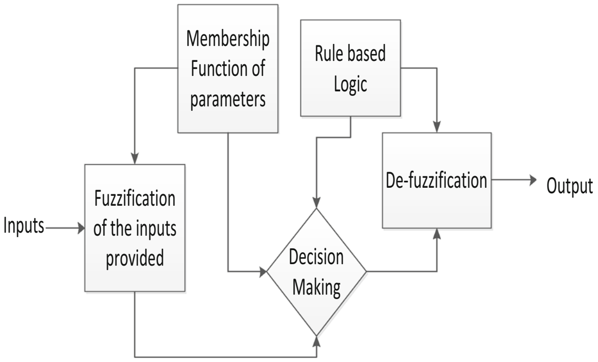

Fig. 3 Fuzzy inference system

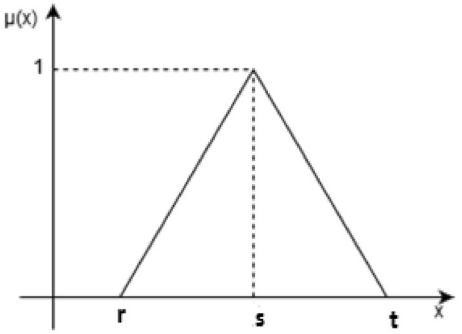

Fig. 4 Triangular membership function

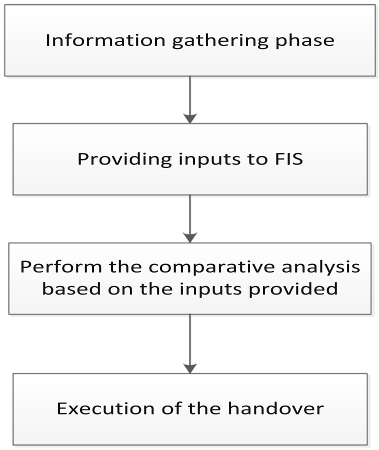

Fig. 5 Phases of handover

4 Design and implementation

As shown in Fig. 1, user is moving in the heterogeneous cellular network zone from 3G to 4G.The block diagram for the Fuzzy Inference System (FIS) is captured in Fig. 6.

As shown in Fig. 6, there are 3 Fuzzy Inference Systems (FIS). The inputs to the FIS are RSS, Channel capacity, velocity, network load. Figure 7 captures the algorithm for

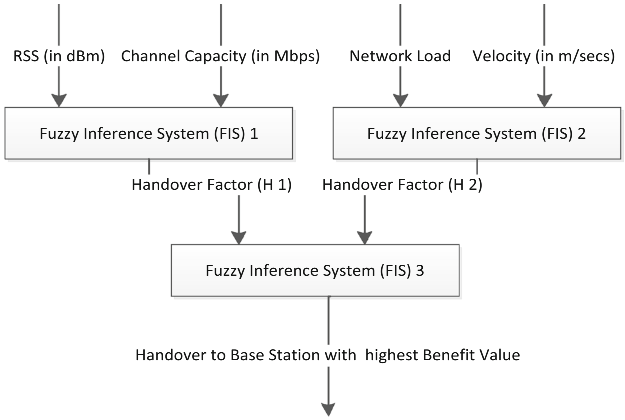

Fig. 6 Block diagram of FIS

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Model ; Vertical Handover Decision Algorithm
based on Free Space Model using Fuzzy Logic

Input Data :
        d ( Distance from Base Station)
        T (Temperature)
        NL ( Network Load)
        $V_u$ ( Velocity of the user)

Calculated Data:
        $P_r$ (Received Power at mobile terminal)
        C (Channel Capacity)
        SNR ( Signal to Noise Ratio)

Output :
        Benefit Value (BV)

Steps to be followed :

    1. Check the Velocity of the User $V_u$
    2. For d = 1 to Total Coverage Distance D
    3. Calculate $RSS_i$ & $RSS_j$ for both $BS_i$ & $BS_j$
    4. If $RSS_j > RSS_i$
    5. Calculate $C_i$ & $C_j$
    6. $RV_i$ & $RV_j$ using FIS
        i.  Define Membership function &
            Rule base considering each
            parameter
        ii. Calculate Benefit Value
    7. Handover to $BS_j$ if $BV_j > BV_i$
       else
    8. Stay on $BS_i$
    9. Repeat step 2 onwards for entire distance.
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Fig. 7 Algorithm for vertical handover

handover in wireless networks. Figure 8 captures the flowchart for Vertical handover.

As shown in Fig. 8, the input parameters are distance from base station, temperature, network load and velocity. The RSS monitoring is done across the entire distance. Once the RSS of the current BS is less than RSS of second BS, benefit value is calculated basis channel capacity, velocity and network. The handover is performed to the BS with highest benefit value.

Table 1 captures the details of Universe of Discourse of the input parameters. Table 2 captures the major rule base for FIS.

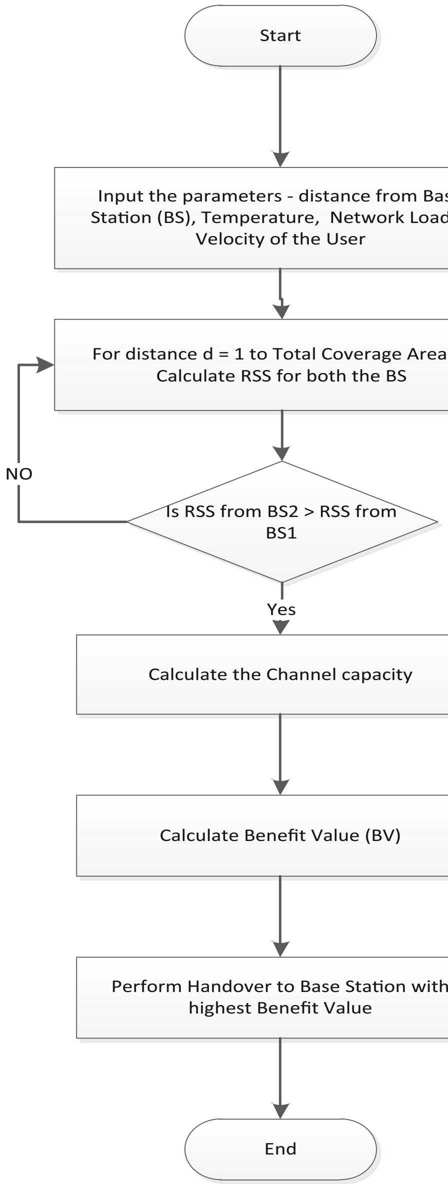

Fig. 8 Flowchart for vertical handover

The Simulation Parameters are captured in Table 3.

5 Simulation and results

We have considered the scenario when coverage areas of base stations are overlapping. The user is moving along line AB, as shown in Fig. 9.

We have considered the practical scenarios pertaining to the overlapping of the coverage areas of the BSs.

Distance between point A& B $(AB, in\,mts) = 2250$.

We have changed the operating frequency of 3G & 4G base stations and observed the variation in the point of

Table 1 Universe of discourse

S. no	Parameter	Unit of measurement	From	To	Max Value
1	RSS	In dBm	– 107	– 48	–
1.1	Low		– 107	– 78	– 107
1.2	Medium		– 107	– 48	– 78
1.3	High		– 78	– 48	– 48
2	Channel capacity	In Mbps	0	50	–
2.1	Low		0	25	0
2.2	Medium		25	50	25
2.3	High		25	50	50
3	Network Load	No of users per base station	0	300	–
3.1	Low		0	150	0
3.2	Medium		0	300	150
3.3	High		150	300	300
4	Velocity	In m/sec	0	14	–
4.1	Low		0	7	0
4.2	Medium		0	14	7
4.3	High		7	14	14
5	Benefit value	(No units)	0	4	-
5.1	Low		0	2	0
5.2	Medium		0	4	2
5.3	High		2	4	4

Table 2 Rule base for FIS

Rule base for FIS 1		
RSS	Channel capacity	Handover factor1
Low	Low	Low
Medium	Medium	Medium
High	High	High
Rule base for FIS 2		
Network Load	Velocity of the User	Handover factor 2
Low	Low	High
Medium	Medium	Medium
High	High	Low
Rule base for FIS 3		
Handover factor HF1	Handover Factor HF2	BV (Benefit value)
Low	Low	Low
Medium	Medium	Medium
High	High	High

handover. As shown in Table 4, we have considered two scenarios for 3G base station and observed the change in point of handover with variation in operating frequency of 4G base station.

Tables 5 and 6 captures the variation in point of handover with changes in frequency for both the scenarios.

Figure 10 captures the variation in point of handover for scenario 1 i.e. Operating Frequency of 3G BS is fixed at 900 MHz and Operating frequency of 4G BS is changed. The handover distance (i.e. point of handover) from point A (centre of 3G base station) is calculated. As shown in Fig. 10, the handover distance (in mtrs) from A (centre of 3G base station) is on Y axis and operating frequency of 4G base station is plotted on X axis.

Figure 10 captures the variation in point of handover for scenario 2 i.e. Operating Frequency of 3G BS is fixed at 2100 MHz and Operating frequency of 4G BS is changed. The handover distance (i.e. point of handover) from point A (centre of 3G base station) is calculated. As shown in Fig. 11, the handover distance (in mtrs) from A (centre of 3G base station) is on Y axis and operating frequency of 4G base station is plotted on X axis.

6 Analysis of results

We have analyzed the results of the scenario 1 and 2 in this section. Table 7 captures the percentage change in the handover distance for both scenarios. Figure 12 shows the comparison of the handover distance for both the scenarios.

Observation: From Fig. 12 we observe that with the change in the frequency of 3G base station from 900 to 2100 MHz, the distance of point of handover from 3G base station decreases. We also observe from Table 7 that with increase in operating frequency of 3G BS from 900 to 2100 MHz, the handover distance (from 3G BS) reduces by 27% approximately.

Table 3 Simulation parameters

S. no.	Parameter	Unit of measurement	Value
1	Network Load on base station	No. of users latched	300
2	Velocity of the User	m/secs	15
3	Transmitting Power	dBm	23
4	Temperature	Kelvin	302
5	Bandwidth for 3G	Mbps	12
6	Bandwidth for 4G	Mbps	20
7	Radius of 3G Base station	mtrs	2000
8	Radius of 4G Base station	mtrs	1500

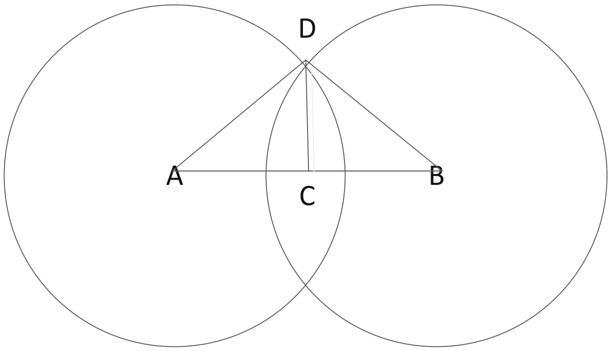

Fig. 9 Figure showing overlapping coverage

Table 4 Scenarios of operating frequencies

Scenario	Operating frequency of 3G base station (in MHz)	Operating frequency of 4G base station (in MHz)
Scenario 1	900	1800, 2100, 2300, 2500
Scenario 2	2100	2100, 2300, 2500

This mainly occurs due to the change in path loss component. The path loss increases with the increase in operating frequency and hence the RSS decreases. This results in faster handover when the 3G BS operating frequency is increased.

7 Conclusion

This research paper captures the design and implementation of vertical handover decision algorithm in heterogeneous cellular networks. We have considered all the important parameters which affect handover in real life scenarios. This algorithm can be used for study of coverage area of BSs for different operating frequencies and varying propagation conditions. This information can be used by network operators for network planning. The transmitting

Table 5 Variation in point of base station for scenario 1

3G base station with frequency (in Mhz)	Point B—4G base station) with frequency (in MHz)	Handover point from A (3G base station) in m
900	1800	1491
	2100	1565
	2300	1607
	2500	1644

Table 6 Variation in point of handover for scenario 2

3G base station with frequency (in Mhz)	Point B—4G base station) with frequency (in MHz)	Handover point from A (3G base station) in mtrs
2100	2100	1118
	2300	1169
	2500	1215

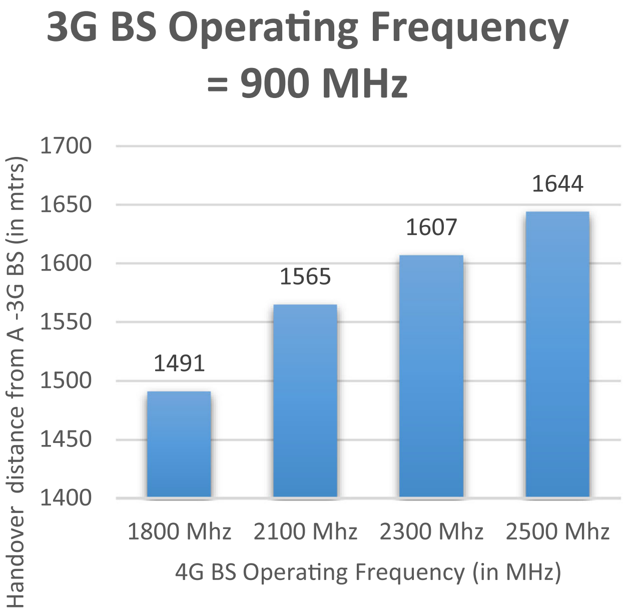

Fig. 10 Variation in point of handover for Scenario 1

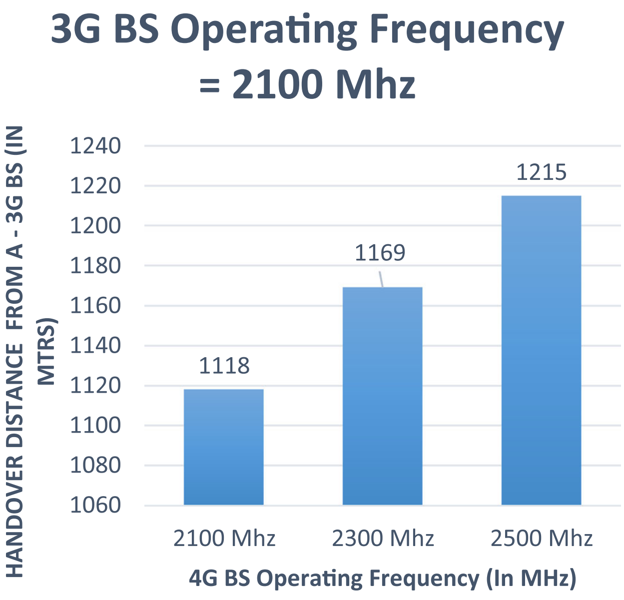

Fig. 11 Variation in point of handover for Scenario 2

Table 7 Percentage change in point of handover

4G Base station operating frequency (in MHz)	Distance of handover point from 3G base station with operating frequency (in mtrs)		Percentage change in distance of handover
	900 MHz	2100 MHz	(In %)
2100	1565	1118	– 29%
2300	1607	1169	– 27%
2500	1644	1215	– 26%

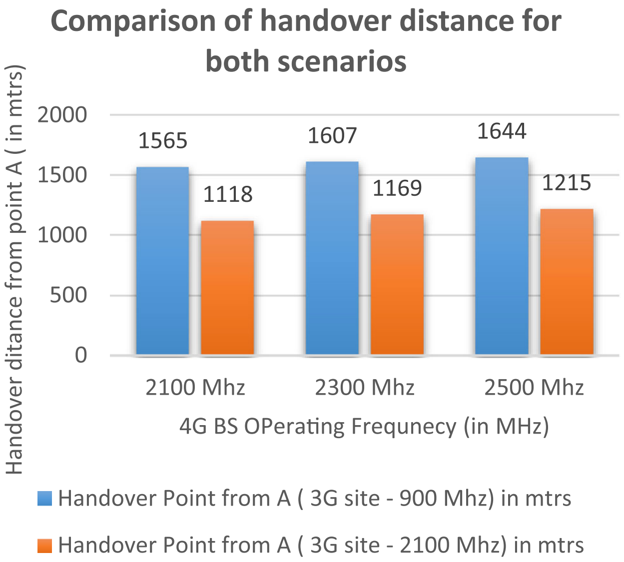

Fig. 12 Comparison of handover distance

powers can be adjusted dynamically to preserve cell identities and perform efficient handover.

8 Future scope

In this research paper, we have calculated the path loss using Free Space Propagation model. In future, we intend to calculate path loss using Okumura model and Hata model. Further, we intend to perform the comparative analysis of handover points based on free space propagation model, Okumura model and Hata model. Also the future scope includes considering the user trajectory at an angle Θ° to the line joining the two base stations (AB) and analyze the changes in the points of handover. We also intend to increase the number of parameters in system model so that it caters to real scenarios with practical values.

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