HetNet security solution using femtocell network architecture and UMTS technology in the millimetre range

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Abstract: Heterogeneous network security is a prime concern in the era where billions of human beings and physical devices will get connected through next-generation technologies like millimetre-wave wireless, the internet of things, artificial intelligence and machine learning. Higher bandwidth in the millimetre range will help to achieve seamless connectivity and tens of gigabits per second data rate. In femtocells, handoff security will play a vital role to avoid call drops. This article focuses on how new handoff security algorithm deployed in the femtocells network by a method that uses Call Admission Control protocol and UMTS technology. Call admission control protocol gives variable quality of services by efficient utilisation of network resources and available bandwidth. The number of handoffs and probability of call drops is less when the user moves from femtocells to macro-cells. Dynamic threshold time reduces number of handoffs and improves handoff security.

Keywords: femtocells; handoff; call admission control; HetNet security; millimetre-wave; UMTS; call drop probability; femtocell access point; handoff threshold; signal to interference plus noise ratio.

Reference to this paper should be made as follows: Chikhale, D.V., Munde, M.M. and Deosarkar, S.B. (2023) 'HetNet security solution using femtocell network architecture and UMTS technology in the millimetre range', *Int. J. Wireless and Mobile Computing*, Vol. 24, No. 1, pp.83–90.

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1 Introduction

Nowadays, the topic of the Heterogeneous Network (HetNet) has gained attention and momentum in industry and academia. Protecting security and privacy has become major concern in new heterogeneous networks as risk can have high significances (Khan et al., 2019). HetNet requires efficient backhaul and simulation tools to meet various requirements like cost, coverage, throughput (Stéphan et al., 2014). When the user is moving, the concept of handoff plays an important role. The user moves out of the coverage area of a registered base station and enters into a new base station area, call control gets transferred to a new base station and the process is called handoff. When users move from macro-cells to femtocells and vice-versa it is called cross-tier handover. The frequency of handover not only brings heavy signalling load but also degrades the user performance (Chaowdhury et al., 2018; Hong et al., 2011). A macro-cell is considered to be the primary tier in two tier networks and femtocells have been considered a promising technology for extending indoor services, improving coverage and capacity (Zhang et al., 2013). Femtocell security, spectrum, regulation are few challenges need to be concerned for UMTS, LTE-A technologies (Abbas, 2021).

There are various databases among that Visitor Location Register (VLR) keeps details of roaming user and then transfers it to Home Location Register (HLR). In the cellular network, Mobile Switching Centre (MSC) along with the base station and mobile station handles the task of handover. If handover is not completed properly, call will get dropped. Femtocells are attracting attention of researchers to increase coverage, capacity to accommodate users and to reduce transmit power in the process of handoff (Wang et al., 2016; Hu et al., 2011; Xenakis et al., 2012). Today because of the large number of cells in a small cell network, mobile switching centres may get burdened so mobile-assisted handoffs are used. Handoff security is essential to avoid delayed handoffs. Handling the authorised user to avoid security threats plays a vital role in handoff which in turn increases handoff delay (Sridevi and Rajaram, 2014).

Hetnet is a network containing nodes with different characteristics such as transmission power and radio frequency coverage area (Bogale and Le, 2015). The open nature of radio propagation enables wireless access anywhere. It becomes the root cause of security, vulnerability in wireless communication. Physical layer security may help the authentication process in complex HetNets in 5G networks. Physical layer attributes are emerging as an effective approach to enhancing wireless security. Handover delay can be reduced by an authentication mechanism (Zheng and Sarikaya, 2009; Wang et al., 2016). Integration of mm-wave and massive MIMO with HetNet is essential to understand the security requirements for next-generation HetNet. In an ultra-dense network as cells come closer probability of a number of handover increases (Chopra et al., 2018; Bogale and Le, 2015). The protocol usage like 802.11r will reduce handoff authentication delay by using handover key (Hu et al., 2011; Zheng and Sarikaya, 2009).

An authentication delay can also be reduced by generating tickets for mesh clients according to zones of mesh router and their communication range (Rathee and Saini, 2019). Authentication prevents unauthorized access when inter-domain and intra domain handover happens (Narmadha, 2019).

Handoffs are classified into various types based on link types and network. It can be classified either as homogeneous or heterogeneous. Various layers like datalink, network, application, authorisation and accounting server cause a delay in the handoff (Sen, 2010). The handover decision is based on a variety of criteria, either mobile hosts or on user preferences (Zdarsky and Schmitt, 2004). It is based on user movement, signal to noise ratio, radio signal strength (Lai et al., 2020). It is difficult to keep association with existing base station when the flag quality corrupts to a level where it is difficult to agree to keep up the association (Abdulhussien and Abdulhussein, 2021). I) Hard handoff: this is a break before make a kind of handoff where the existing base station providing service is discontinued first and the latter call gets connected to the new base station. II) Soft handoff: this is a make before break kind of handoff where the existing base station gets disconnected after a call gets connected to new base station or channel. III) Intersystem handoff: this is where the call gets transferred from one MSC to another MSC. IV) Mobile-

Assisted Handoff: In which a call gets transferred from one mobile station to another mobile station without the involvement of the base station and MSC. V) Intrasystem handoff: in which call gets transferred from one base station to another base station under one MSC.

In ultra-dense networks, millimetre-wave communication is an excellent choice as it is well suited for small distance and line of sight communication. But the frequency of handover and handover probability are the important parameters for handover security of HetNet. Call drops results due to handover failure and can reduce the revenue of the operator up to a greater extent. The velocity with which mobile is travelling should also be considered while developing the handover algorithm (Pahal, 2017).

This article focuses on frequency of handover and handover probability aspect. The new handover security algorithm reduces the number of handoffs and the probability of handover in dense environments and helps to improve handover security. In the previous work, the attempts are made with parameters like radio signal strength, Signal to Interference plus Noise Ratio (SINR). In this article new method using Call Admission Control (CAC) protocol is suggested and implemented, which gives the better outcome to achieve handoff security when compared with existing work carried in the lab of South Korea using femtocell architecture, call admission control Protocol and UMTS technology. The work was published first in 2009 and then in 2018. The new method using CAC and new handoff threshold time gives improved outcome for the sample of 40 users tested by simulation method. Thus, that new method gives better security in the process of reduction of call drops, probability of handover and helps to increase of revenue of the operator.

It is achieved by means of reducing the probability of handoff and handover failures (Verma et al., 2019). The article is further divided into three sections. Section 2 is Femtocell System Architecture and Flowchart, Section 3 is Simulation results and Section 4 is Conclusion.

2 Femtocell system architecture and flowchart

In a small cell network of femtocells, handoff takes place from macro-cell to femtocells and from femtocells to macro-cells. Call handling becomes challenging when the user moves from macro-cell to femtocell. Handoff security is improved when the numbers of handovers are reduced and the user moves from macro-cell to femtocell. Hetnet security is a prime concern to us. This new approach gives an optimum security solution when compared to existing solution for parameters unnecessary probability of handover and number of handoffs given by Chaowdhury et al. (2018). Unnecessary handover endures a serious problem in the femtocell network. The network can be formed using UMTS technology. UMTS WLAN is proposed to boost security and minimise handover delays. It consists of Femtocell Gateway (FMG) and Femto Access Point (FAP) as primary components. FAP consists of a Femto Management System (FMS).

The handoff process is divided into two phases, handover preparation phase and handover execution phase. In the handoff preparation phase information is gathered and a handover decision is taken. Mobile host or network decides the time of handover and is called mobile assisted or network-assisted handoff. In the execution phase, either network or mobile host executes and controls the actual handover process (Zdarsky and Schmitt, 2004). Mobile equipment collects information about the number of handover candidates those requires authentication for security purpose. Depending on radio signal strength the elite candidate is determined and the mobile station initiates handover request to connect to new access point. Radio resources are required in this approach, so numbers of handoffs are reduced to get an optimised solution.

In femtocell to macro-cell handover, time required for handover should be small but it doesn't require complex interference calculation and authorisation check in this type of handover. Frequent and unnecessary handoff reduces the Quality of Service (QoS) level and decreases the capacity of a system. This problem arises when high-speed user moves from macro-cell to femtocell and vice-versa. Three parameters have been considered for new CAC method, received signal level, time for a minimum required signal level and signal to interference level. A proper threshold time is selected by service provider for handover decisions, so minimum signal level required for movement of the mobile station from macro-cell to femtocell is achieved. Threshold time plays crucial role along with the interference level in determining handover decisions to be taken in new CAC, larger the threshold time lesser is the number of handoffs. CAC is used to starve the best effort traffic and gives variable quality of services by efficient utilisation of network resources and available bandwidth (Mamman et al., 2017; Badri et al., 2015). Simulations are done for two approaches, without call admission control and with call admission control for thresholds time of 10 s and 20 s respectively. 3GPP UMTS network is used in macro-cell and femtocell integrated network. Mobility management has a lot of significance in wireless networks and for mobility enhancements in small cell networks (Hong et al., 2011). SINR parameter is considered for handover between macro-cell to femtocell and optimisation of it will enhance the performance of femtocell network. Frequent handovers between small cells and HetNet cause potential threat on communication privacy, security and access control (Zhao et al., 2021). FGW, FMS and FAP act as a concentrator to provide connectivity with core network. Data traffic flows from FAP via FGW to the Radio Network Controller (RNC) and finally to target femtocell. The FAP has preregistered users that helps to reduce the number of signals in femtocell so macro-cell to femtocell handoffs are lowered.

The mobile stations moves in the HetNet. Femtocell coverage area is circular and radius is 10 metres. The average velocity of a mobile station in the femtocell is 0.9 km/hr, while average call duration and user velocity have exponential distribution (Chaowdhury et al., 2018).

Femtocell system architecture consists of a core network, access network and mobile equipment. The access network is formed by enodeB and devices like routers and access points used where two mobile stations communicate through the FAP. Interface Iu connects the core network and the access network, while interface Uu links the femtocell access network and mobile equipment. Data is routed from the core network to access network and to the end-user. Access device enodeB acts like a bridge between two communicating mobile terminals.

Figure 1 shows internal femtocell system architecture which consists of circuit switching, packet switching, and external network elements. In circuit switching connection is established, reliability is checked and then data transfer takes place. Once data transfer is complete, connection is terminated. In packet switching, some flexibility is observed. Other elements are MSC, serving general packet radio service support node (SGSN), gateway general packet radio service support node (GGSN), interfaces Iu-cs and Pu-cs are used for circuit switching and packet switching respectively. RNC functions like base station controller in GSM, nodeB is used in UMTS, and femtocells, Public Switching Telephone Network (PSTN), Internet Multimedia System (IMS) and internet forms core network of femtocell architecture. The large number of femtocells communicates to nodeB, which sends the desired information to the RNC and it forwards to FMG. MSC handles data in circuit switched network with the help of Iu-cs interface while packet switched network's data are handled by SGSN through interface Iu-ps.

Data is processed by IMS core network and is sent to external networks like PSTN or internet. Millimetre-wave technology is well suited for dense networks, where thousands of femtocells are handled for high-speed data transfer. It consists of RNC, security gateway, ISP network and FAPs. RNC handles a large number of femtocells that uses different architecture used by the 3GPP and transfers data to FAPs through security gateway and ISP network using interface Iu-h. FMG connected to RNC using Iu-h interface functions like nodeB (Chaowdhury et al., 2018).

The call gets transferred from macro-cell to femtocell using handover phases. Optimisation is done based on selection, reselection and RRC management. The FAP has RRC while nodeB has no RRC that is the basic difference between the femtocell access network and UMTS-based macro-cell network. Macro-cell to femtocell handover is most challenging and requires complex interference calculations while in femtocell to macro-cell handover interference calculations are simple, authorisation check and less functionality required as compared to macro-cell to femtocell handover. The best possible neighbour list of FAP is required to select close FAP and once finalised mobile station has to initiate connection and complete handover. Measurement report send by the mobile station to FAP should consist of interference level otherwise the quality of service and capacity can be affected and unnecessary handoffs may increase then a modified handover policy is needed (Chaowdhury et al., 2018).

Call Admission Control (CAC) is a practice or process of regulating traffic volume in voice communication. In voice over IP mobile networks has to maintain a certain quality of voice which is required. It works by regulating total unlimited bandwidth, the total number of calls and the total number of packets or data bits passing through specific points per unit time. The actual content of a call may not be known to the descriptor. It uses different algorithms used in the handover process to accept handover calls by the femtocell access point.

Figure 2 demonstrates a flowchart for CAC to accept handover calls by the FAP. Femtocell signal level is checked by comparing threshold level for the specific time interval. If the signal level is not greater than the threshold level, Eb/Io that is signal bit energy to the interference ratio will be checked against the threshold.

Figure 1 Internal femtocell system architecture

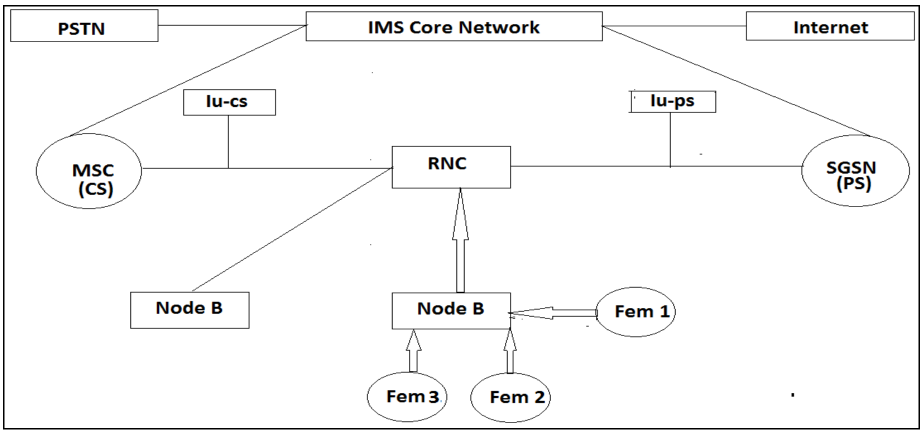


Figure 2 Flowchart: CAC to accept handover call by FAP

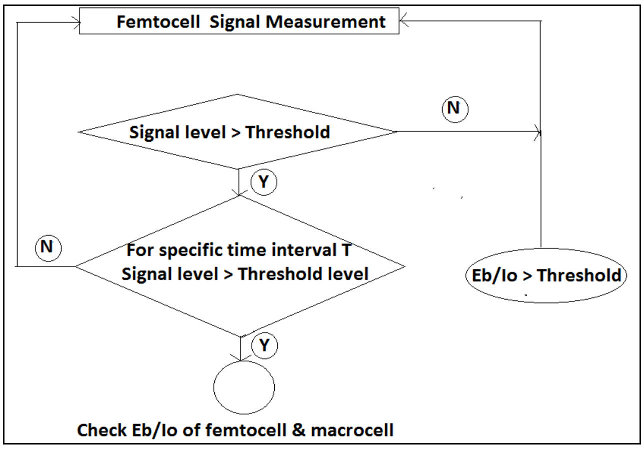
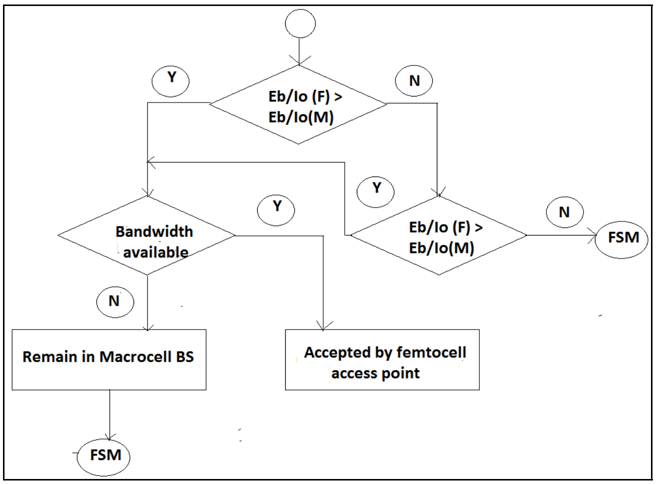


Figure 3 depicts a flowchart for handover decision in continuation with Figure 2. If the Eb/Io of a femtocell is greater than the Eb/Io of a macro-cell, macro-cell bandwidth availability will be checked and if it is available, accepted by the FAP, otherwise retained in macro-cell base station. If the Eb/Io of a femtocell is not greater it will be checked against the threshold and control is transferred to the femtocell management system. Information flows from mobile station to FAP to FGW and from the gateway it goes to the core network consisting of MSC, cs-core, SGSN, ps-core, IMS core network, PSTN and internet. Interfaces used are Iu-cs, Iu-ps, Iub (between FGW and RNC) and Iuh (between FGW and ISP).

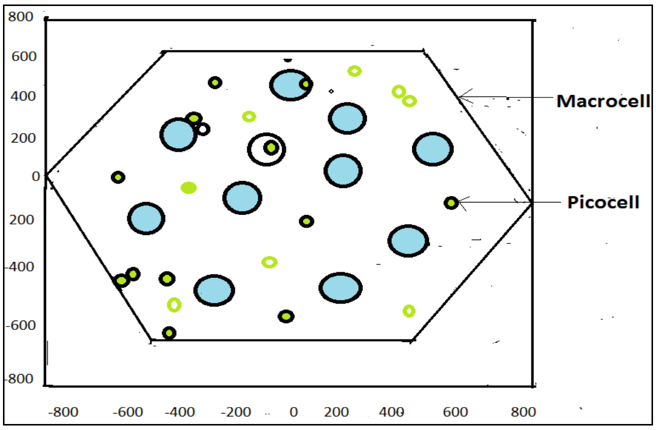
Figure 3 Flowchart: CAC to accept handover call by FAP



In macro-cell to femtocell handover, some modification in network architecture and protocol architecture is needed to change signal flow for a handover procedure. The larger the value of threshold time lowers the number of handoffs. Unnecessary handover optimisation using proper CAC and RRC is done that leads to reduction in packet loss, increase in throughput and reduced signalling cost (Xenakis et al., 2012). The threshold level is the minimum level of a signal that must be needed to handover a mobile station from macro-cell to femtocell. Threshold time (T) specified by the operator must be maintained when the mobile station moves from macro-cell to femtocell for that Tmin. An assumption made is hundred FAPs within a macro-cell coverage area from which we request for a single femtocell from the average result of hundred femtocells. Parameters that need to be considered are the shape of femtocell, coverage, and radius, the average velocity of a mobile station in the femtocell coverage area, average call lifetime after the handoff from macro-cell to the femtocell, call lifetime, user velocity and the number of FAPs within a macro-cell. Simulation results obtained using parameter CAC with time 10 s and 20 s, respectively.

Figure 4 shows a cell of 800 × 800 square metres which consists of small cells obtained as shown. It shows the movement of users from the macro-cell to the femtocell or picocell and from the femtocell to the macro-cell. Handovers are more when the user moves to femtocell from macro-cell because the handoff period is short and the user can be a high-speed user. This type of handoff always remained a serious problem because along with the speed of the user its position in femtocell whether it is at the centre or boundary is also important because that decides how much time the user can be observed in femtocell which already has a small coverage area. So, the probability of unnecessary handoff is always there when the user moves from macro-cell to femtocell and vice-versa. It is expected there is smooth handover when the user moves from femtocell to macro-cell. Handover assure to provide good quality of service and continuous communications to maintain overall network performance in 5G (Tanveer et al., 2022).

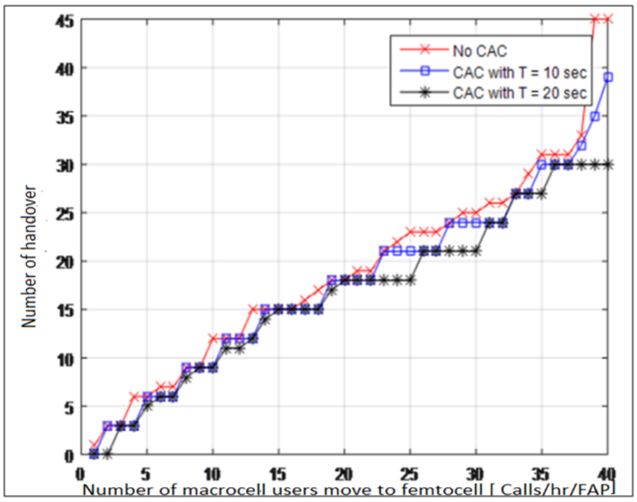
Figure 4 Heterogeneous network



3 Simulation results

From Figure 5, it is clear that the number of macro-cell user's move to femtocell (Calls/hr/FAP) is plotted versus a number of handovers. Without CAC number of handovers are 45 for 40 users. The number of handovers increases as the number of users increases while with a threshold time equal to 10 s, number of handovers reduced to 38. The number of handovers with a threshold time equal to 20 s is equal to 30. As threshold time increases the number of handovers are reduced and handoff security is improved. This model is simulated by using 40 users. If it is implemented on a larger scale, it will not only enhance the quality of communication but also increase the revenue of operators.

Figure 5 Number of handovers versus user



From Figure 6, it is clear that unnecessary handover probability without CAC is 0.98. It goes on increasing when the number of users interested in handover increases to 38. The probability of CAC with a handoff threshold time of 10 s is 0.2 on an average and for 20 s it is 0.15 on an average. These optimum results are obtained with the implementation of this approach when compared with existing solutions given by Chaowdhury et al. (2018).

Figure 6 Probability of unnecessary handovers versus the number of users

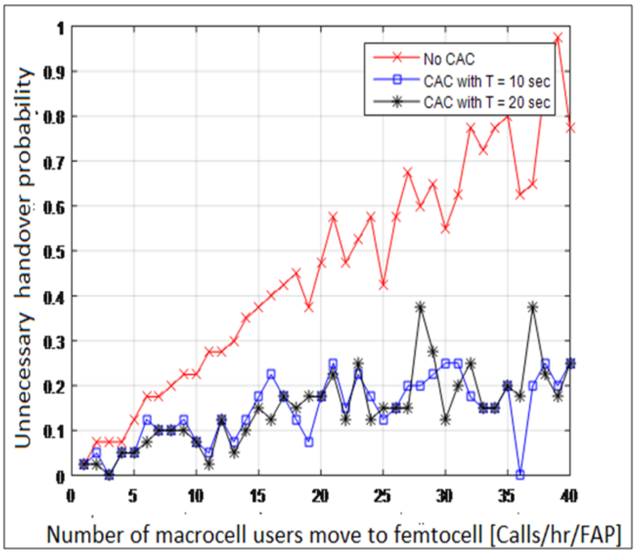


Table 1 shows comparison of proposed work using CAC protocol with existing literature.

Table 1 Comparison of proposed with existing work

Sr. No.	*Ref. & Year*	*No. of users*	*Protocol used*	*No. of handovers for duration*		*Probability of successful handover for duration*	
				10 s	*20 s*	*10 s*	*20 s*
1	Stephan et al. (2014)	15	CAC	18	16	–	–
		25		32	28	–	–
		30		39	33	–	–
		35		45	38	–	–
2	Omitola and Srivastava (2017)	40	EHA	60	80	–	–
3	Neeraja and Abhishiktha (2019)	40	HO Algorithm	–	–	0.6	0.7
4	Sapkale and Kolekar (2020)	–	HAD	15	30	0.75	0.75
5	Proposed work	15	CAC	15	15	–	–
		25		21	18	–	–
		30		23	21	–	–
		35		30	28	–	–
		40		–	–	0.8	0.85

4 Conclusion

HetNet security is of prime concern in next-generation networks which can be achieved in different ways. A result obtained with CAC protocol implementation reduces the number of handoffs, probability of unnecessary handovers and hence the call drop. An increase in threshold time reduces the number of handovers. For 20 s, with 40 users and with CAC, handoffs obtained are 30, while for 10 s with 40 users and with CAC handoffs obtained are 38. When compared to without CAC approach they are 45. Thus, the number of handovers are reduced with CAC approach and hence handover security improved. Unnecessary handover probability is 0.78 without CAC while it is 0.25 with CAC for time 10 s and 20 s respectively, when plotted against number of macro-cell users move to femtocell (Calls/hour/FAP) for 40 users. Unnecessary handover probability with CAC reduces to greater extent when compared to non-CAC and other algorithms. A reliable and efficient handover scheme is possible using CAC between macro-cell and femtocell. System simulation results are for 40 users. It can be tested for more users using a testbed. Hetnet security model will play a huge role in next-generation networks of ultra-high-speed communication where billions of users and devices are operational.

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