CLUSTER-BASED MULTIHOP SYNCHRONIZATION SCHEME FOR FEMTOCELL NETWORK

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ABSTRACT: Femtocell technology has been drawing considerable attention as a cost-effective means of improving cellular coverage and capacity. It is connected to the core network through an IP backhaul and can only use timing protocols such as IEEE1588 or Network Time Protocol (NTP). Furthermore, the femtocell is installed indoor, and cannot use a GPS antenna for time synchronization. High-precision crystal oscillators can solve the timing problem, but they are often too expensive for consumer grade devices. Therefore, femtocell Base Station (fBS) synchronization is one of the principle technical trends in femtocell deployment. Since fBSand macrocell Base Station (mBS) network operates on the same frequency under a licensed spectrum, fBS network can interfere with the macrocell network. In addition, fBSs can also interfere with each other if multiple units are in close proximity. Furthermore, in a flat fBS structured network using IEEE 1588 synchronization algorithm and fBS-fBS synchronization scheme creates offset and frequency error which results inaccurate synchronization. In order to reduce offset and frequency error (skew), this paper proposed a cluster-based multihop synchronization scheme to achieve precise in fBS neighbor nodes. The proposed scheme is able to reduce the offset and skew significantly.

ABSTRAK: Teknologi *Femtocell* telah menjadi tumpuan sebagai alat yang kos-efektif dalam memperbaiki liputan mudahalih dan kapasiti. Ia menghubungkan jaringan teras melalui IP *backhaul* dan hanya boleh menggunakan protokol masa seperti IEEE1588 atau Protokol Jaringan Masa (NTP). Seterusnya, femtocell dipasang di dalam, dan tidak boleh menggunakan antena GPS untuk sinkronisasi masa. Osilator Kristal yang tinggi kejituannya boleh menyelesaikan masalah masa, tetapi ianya mahal bagi gred peranti consumer. Oleh itu, sinkronisasi Stesen Asas femtocell (fBS) adalah salah satu tren teknikal prinsip dalam *deployment* femtocell. Memandangkan fBS dan jaringan Stesen Asas makrosel (mBS) beroperasi pada frekuensi yang sama di bawah spektrum lesen jaringan fBS boleh mengganggu jaringan makrosel. Tambahan pula, fBS juga boleh mengganggu antara satu sama lain jika unit pelbagai adalah *close proximity*. Tambahan lagi, bagi struktur jaringan rata fBS menggunakan algorisma sinkronisasi IEEE 1588 dan skema sinkronisasi fBS-fBS mencipta *offset* dan ralat frekuensi yang menyebabkan ketidaktepatansinkronisasi. Bagi mengurangkan *offset* dan ralat frekuensi (skew), kajian ini mencadangkan multihop berasaskan kluster skema sinkronisasi bagi mencapai kejituan dalam mod kejiranan fBS. Skema yang dicadangkan boleh mengurangkan offset dan *skew* dengan berkesan.

***KEYWORDS*:** *femtocell base station (fBS); synchronization; frequency division multiple access (FDMA); inter-cluster, intra-cluster*

1. INTRODUCTION

The femtocell extends network coverage and delivers high-quality mobile services inside residential and business buildings with the better cellular network coverage, and has triggered the design and development of new structured cellular standards such as WiMAX (802.16e), the Third Generation Partnership Project's (3GPP's) High Speed Packet Access (HSPA) and LTE standards, and 3GPP2's EVDO and UMB standards. The communication link of the Femtocell may be one of Wide Area Network (WAN) technologies such as Asymmetric Digital Subscriber Line (ADSL). Since a public network is used to establish the connectivity between the femtocell and core network elements that presents a set of problems for operators. Moreover, the femtocell architecture is much more different than existing cellular networks. However, femtocell introduces new challenges to the telecom industries in terms of synchronization issues which is considered corner stone for proper working for femtocell. The main challenging concern in femtocell synchronization is that all the data and control traffics travel through IP broadband network. The IP broadband network is usually owned and managed by third party and not by the mobile operator, which is complicated the synchronization. In addition, the conventional algorithms and schemes has the clock offset and frequency error which degrades the synchronization accuracy and as well as throughput. Unsynchronized fBSs may cause harm interferences and wrong handover dictions. In this paper the current femtocell synchronization techniques are investigated. Possible improvements and recommendation for each method is identified. Cluster-based multihop synchronization scheme proposed in order to reduce the clock offsets, skew and increase the synchronization accuracy.

The rest of the chapter is organized as follows. Section 2 presents femtocell network infrastructure, Section 3 analysis of related works, Section 4 contribution, in section 5 performance evalution and section 6 summarizes the chapter.

2. FEMTOCELL INFRASTRUCTURE

A recent development is femtocell, also called home base stations, which are small size short-range low-cost low-power(<10 mW) IP backbone network based on cellular radio systems which are plugged to residential digital subscriber line (DSL), a separate radio frequency (RF) backhaul channel or cable broadband connections to provide improved better indoor signal strength, commonly unattainable by macrocell coverage operating at higher frequencies and increased throughput for mobile data services directly at home. Interestingly, with the introduction of the femtocell technology, the cellular systems come closer to WiFi through architecture, operating frequency, services offered and data rates**.** Table 1 points the femtocell specifications.

Table 1: Femtocell specifications [2]

Item	**Femtocell Specifications**
Data rates	7.2 – 14.4Mbps
Operation Frequency	1.9 – 2.6GHz
Power	10, 100mW
Range	20-30m
Services	Voice, video, and data

Figure 1 illustrates how femtocell connects to the service provider's network to establish the connectivity between femtocell and core network elements such as security Gateway, Femto Gateway, Clock servers via broadband, typically cable modems and digital subscribers lines (DSLs). Signals are routed from the home or office from a user's cell phone over the internet and the provider's base station. In terms of synchronization, the femtocell will therefore see some synchronization messages being transported over the public network.

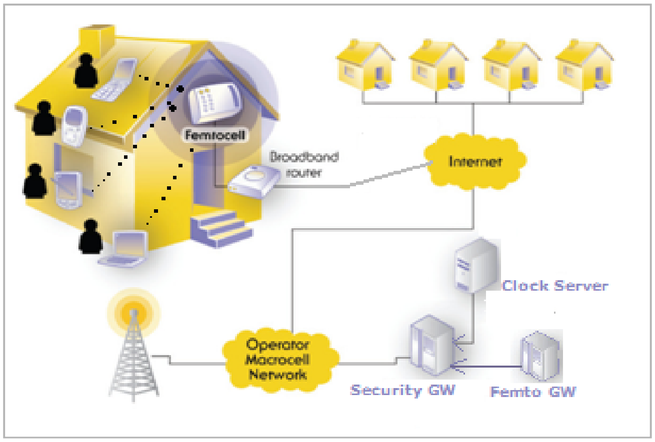

Fig. 1: A femtocell network architecture [2]

Figure 2 illustrates the fBS operation structure in wireless backhaul network.

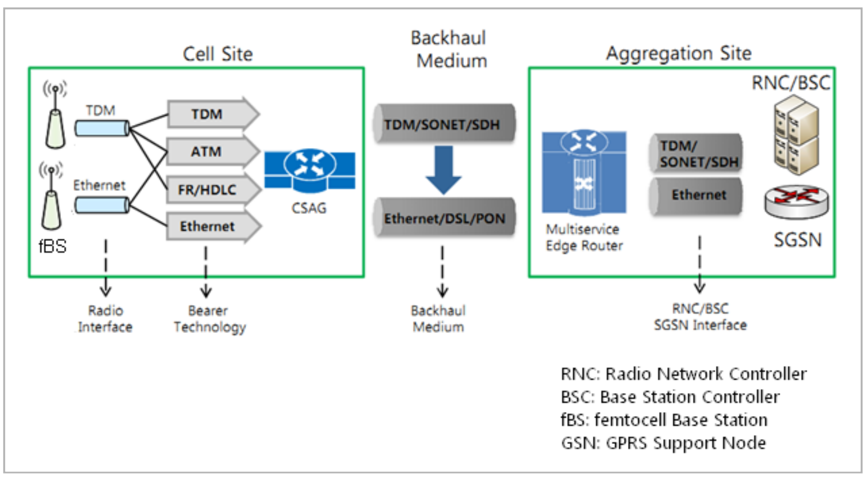

Fig. 2: Femtocell Base Station in wireless backhaul network structure.

3. RELATED WORKS

In the conventional system femtocell suffers from network overhead, bandwidth consumption, misalignment message and offset. In this circumstance, network does not perform precise synchronization. To overcome these issues, researchers have put forward their efforts for developing algorithms and schemes, (Sungwon. [3], Hwang [4], Mills[5], [6], Peng [7], [8], Wada [11]).The paper [3] enhanced synchronization algorithm in order to estimate the asymmetric ratio of downlink and uplink data rate for the communication link (ADSL and VDSL using IEEE 1588) with enabling precise evaluation of offset value in the slave clock. The Block Burst Transmission for Asymmetric Ratio calculation is illustrated in Fig. 3. Due to the enhanced synchronization algorithm, it is possible to lessen offset for the time synchronization in a slave clock according to the scaling factor of the asymmetric ratio (R) and the Sync message transmission delay for downlink (1 ms, 10 ms and 100 ms). Since, it allows the accurate value calculation of the asymmetric ratio for downlink and uplink efficiently using block burst transmission between the master clock and the slave clock. In paper [4] recommends autonomous group generation and merging scheme of femto BSs with a synchronization algorithm within a group as several femto BSs are positioned in uncoordinated and unplanned way. Within a group femto BSs can synchronize to a reference femto BS using multi-hop synchronization path based method, which doesn't need iterations for full network synchronization. The multi-hop based synchronization overcomes the path loss effect that improve the network synchronization performance compared to the conventional single-hop based scheme that a BS directly synchronizes to a reference BS. This multi-hop based scheme is compared to the conventional single-hop based scheme which allows a BS to synchronize directly to a reference BS.

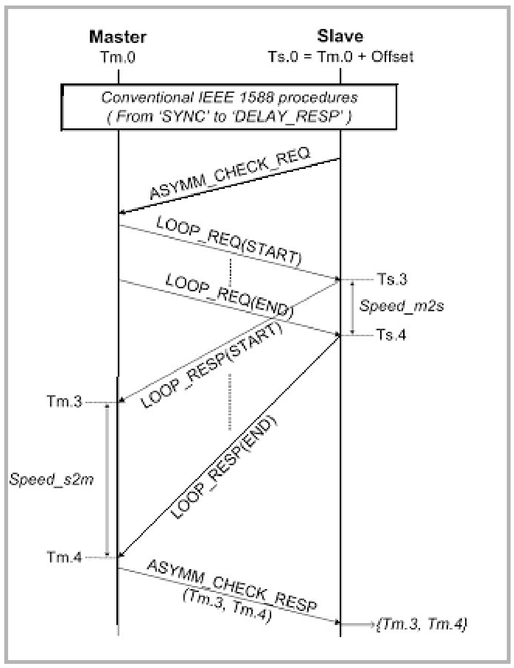

Fig. 3: Block burst transmission for the asymmetric ratio calculation [3]

However, if the distance between the synchronizing femto BS and the reference is short enough, the hop count need not to be increased. In order to reduce interference between different cells, ensuring smooth hands-offs from cell to cell, and achieve seamless operation the overall network needs to be synchronized, a new distributed clock synchronization scheme for heterogeneous networks is proposed in paper [9]**.** This scheme can significantly reduce the clock drift, message overheads between macrocells and femtocell through employing clock drift information which are available at user-equipments (UEs) to precise the synchronization between non-interacting femtocells and macrocells. However, it can be found that nodes suffer for accurate timing with faster convergence and more accurate CDR estimation. The investigations are required in order to achieve more resilient and accurate timing synchronization. Another method of time synchronization is proposed in paper (Xiaoyan [10]). The proposed method updates the slave clock model in time synchronization that is implemented through exchanging the messages. These messages are transmitted in offset calibration, and it does not add any communication cost. With the help of drift compensation, the increase speed of the difference between the time on slave clock and the time on master clock is reduced and it outperforms the conventional synchronization method. In practical application, the communication links are asymmetric. Though combining drift compensation and asymmetric communication, the precision of time synchronization is significantly improved. The average bias error of the time on slave clock as a function of the asymmetric ratio. Mobile Station assisted receiver-receiver synchronization strategy proposed for fBS neighbor nodes in order to get the synchronization accuracy [8]. This scheme followed the reference broadcast synchronization (RBS) to reduce the clocks offset and skews by using the MS and mBS. Figure 4 shows the receiver-receiver synchronization scenarios where two fBS nodes considered.

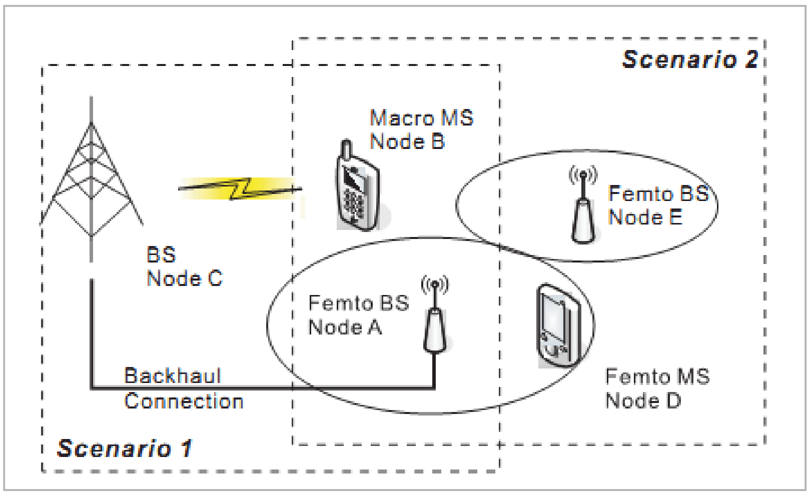

Fig. 4: The Two Femtocell Synchronization Scenarios [8].

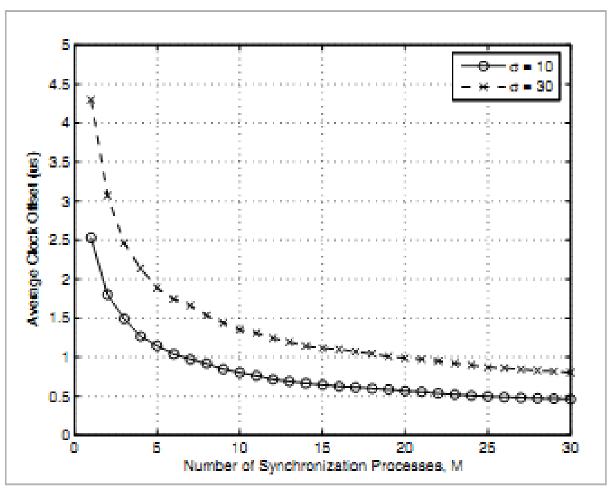

Fig. 5: Average clock offset in different receive delay difference standard deviation, σ [8]

This scheme is fully dependent on Mobile Station and mBS where a reference node is used to synchronize the fBS nodes. In contrast, this strategy is not fully covered in all situations if there has no MS for a long time in any of fBS network. In addition, this reference broadcast may flood the message in the fBS network and which results the network overhead. Consequently, the clock offset and skews are not minimized in the as the fBS network needs to make it decentralized co-ordination which is demonstrated in Fig. 5 and Fig. 6. In receiver-receiver synchronization they achieved 2.5 microsecond (μs) for clock offset and frequency accuracy achieved up to 250 parts per billion (ppb). However, the proposed scheme is able to minimize the clock offset and skews better than the mobile station assisted synchronization scheme in order to precise synchronization. Moreover the related works are summarized in Table 2.

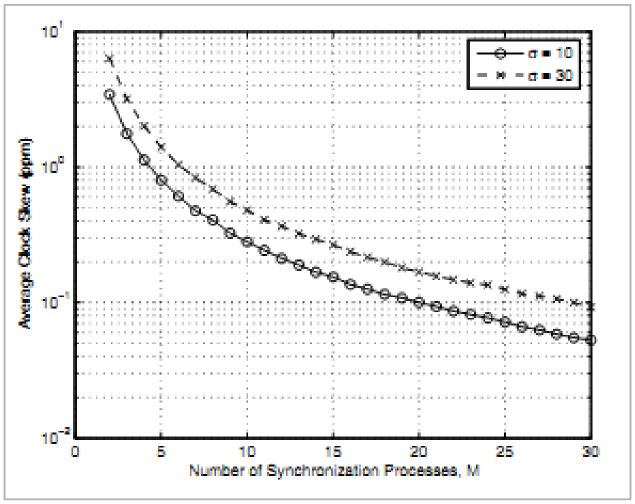

Fig. 6: Average clock skew in different receive delay difference standard deviation, σ [8].

Table 2: Summary of related works.

Method	Advantages	Drawbacks
IEEE 1588 Precision time protocol (PTP) [3]	a. Can synchronize with independent clock. b. In IP based cellular network, it is applicable for synchronizing symmetric communication link. c. fast re-synchronization is possible when system changes occur d. synchronization of clocks are done with various precision, resolution and stability e. Offers low-cost implementation in multicast messaging networks such as Ethernet	a. Misalignment of the time of the master clock and the slave clock. b. Not applicable for synchronizing asymmetric communication link. c. Requires hardware assistance as well as upgrading the network devices d. work only for a few subnets (locally)
Enhanced time synchronization algorithm [4]	a. Optimize the Offset (bias error) for the asymmetric IP based communication links.	a. Inefficient for asymmetric backhaul link.
Receiver-Reciver synchronization scheme [7]	a. Clock Offsets and Skews is minimized.	a. For large number of fBS node this scheme will make network overhead by generating the message flooding
Multihop synchronization scheme [4]	a. Overcomes the path loss effect that improve the network synchronization performance compared to the conventional single-hop based scheme	a. Nodes suffer for accurate timing with faster convergence and more accurate CDR estimation
MS-assisted Receiver-Reciver synchronization scheme [8]	a. Followed reference broadcast synchronization and clock offsets and skews minimized.	a. This scheme will make network overhead by generating the message flooding for a large number of fBS node
Frame timing synchronization [11]	a. Needs to correct the effect of propagation delay time.	a. Estimation error of the distance may create misalignment of transmission timing.

4. CLUSTER-BASED MULTIHOP SYNCHRONIZATION SCHEME

A Cluster-based Multihop synchronization scheme is proposed with the purpose of minimizing the network overhead and clock offset as well as bandwidth consumption. Figure 7 illustrates the proposed synchronization strategy for fBS nodes. In the beginning, the fBS node initializes the synchronization process in periodically. Then fBS node checks out whether the synchronization clock information is received from the macro base station or not. If the node receives synchronized clock from mBS, then the fBS nodes will be synchronized along with its IP address and cell identity. Otherwise it will go for the MS assistance checking. In this case, the fBS nodes will synchronize if only they get the MS assistance. However, if the fBS nodes do not get MS assistance, then the nodes will check for broadband connectivity in order to get the most recent clock synchronization. Therefore, IEEE1588 clock server will synchronize the fBS node. However, in some circumstances, if the bandwidth is limited for updating the clocks, then the synchronization process will be problematic which results in increasing clock offsets and delay time. To overcome these problems, fBS node can use the proposed self-organized synchronization scheme to be synchronized by other synchronized fBSs.

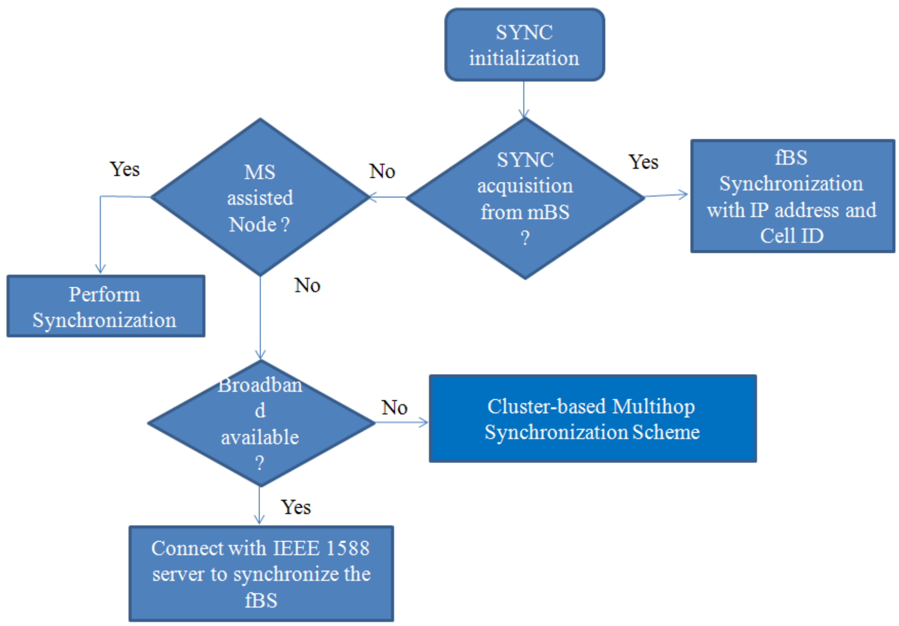

Fig. 7: The proposed synchronization strategy.

The proposed scheme mainly separates the fBSs through cluster, which involves clustering formulation, inter-cluster time one hop and multihop synchronization. Cluster formation is the initial process performed based on time and distance. In this scheme, the two way time exchange techniques are employed to conclude the time synchronization between neighbor nodes and cluster heads through establishing a hierarchical topology or flat structure. For the cluster synchronization Intermediate Node (IN) selection is needed to find the latest Sync message to update each of CM inside cluster. In Fig. 8 the IN selection procedure is shown through flowchart. The total schronization procedure for the inter-cluster is dipicted in Fig. 9. Figure 9 illustrated that after two IN selection clusters start to synchronize each of CM.

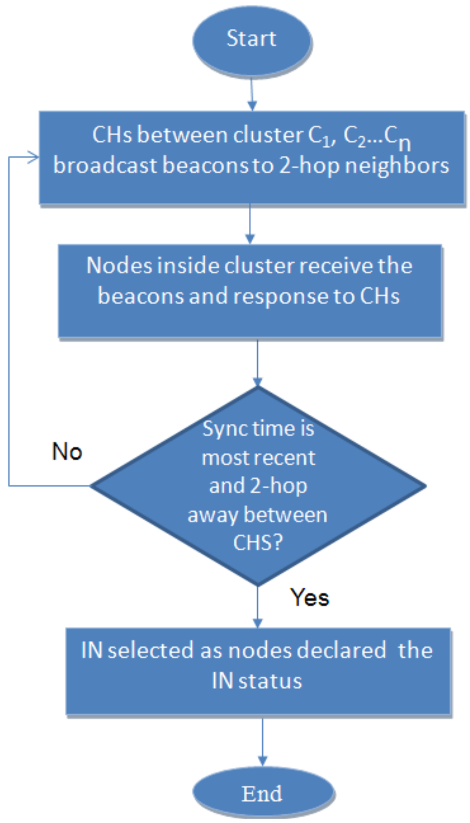

Fig. 8: Proposed Intermediate Node (IN) selection procedure.

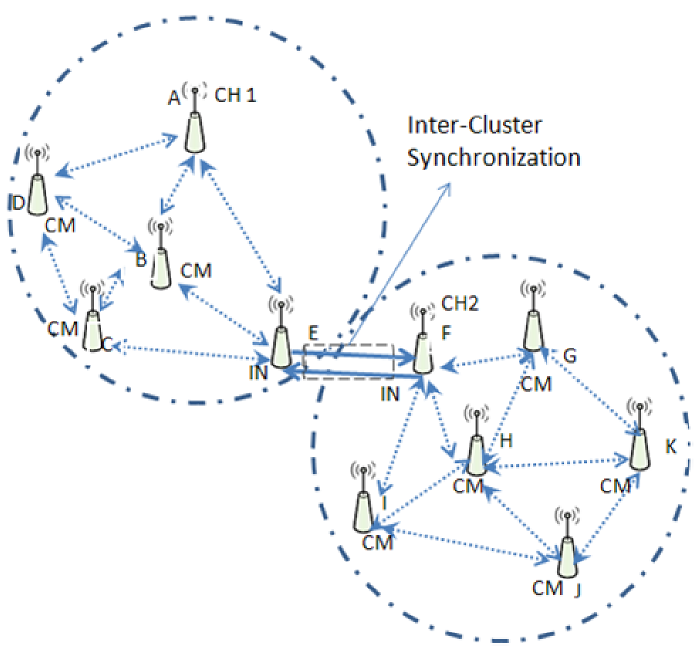

Fig. 9: Proposed Inter-cluster synchronization procedure.

5. PERFORMANCE EVALUATION

In order to achieve better synchronization accuracy, performances of the proposed scheme evaluated. The analytical approach results in satisfactory level of synchronization accuracy for a femtocell network. Table 3 outlines the system paremeters.

Table 3: System parameters.

Parameters	Value
Network Size	200 x 200 m^2
Transmission range	30 meter
Cluster radius	30 meter
Delay difference standard deviation (σ)	10 µs, 15 µs, 20 µs, 30 µs
Distance	0-30 meters
Number of node	10, 25, 50, 100, 200
Number of synchronization process (M)	25

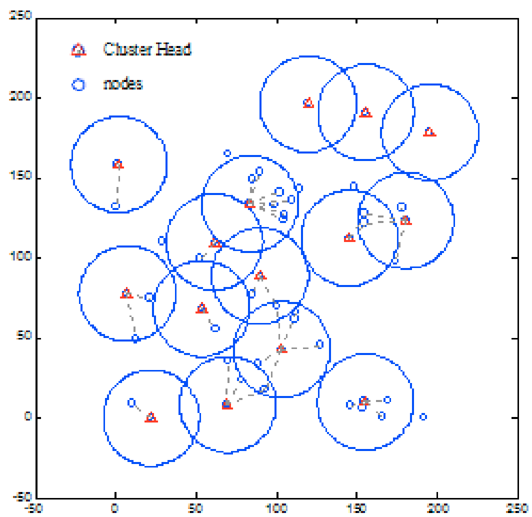

Fig. 10: Cluster head section and cluster formation for 50 nodes.

In Figure 10, the network size is considered to be 200 x 200 sized areas where 50 nodes are created randomly and this is followed by the selection of 15 CH considering the random clock time and minimum distance. As CH is already created, it starts dominating all the CMs and forms the cluster. In some cases, some of the nodes may not join the cluster because of unsatisfactory clock time and distance.

From Fig. 11, the clock offset can be tabulated in Table 4. Table 3 suggests that the clock offset can be minimized to 1.32 microseconds which is better for synchronization accuarcy.

Table 4: Average clock offset.

Number of Nodes	Average clock offset					
	M=1		M=10		M=25	
	σ= 10 µs	σ= 30 µs	σ= 10 µs	σ= 30 µs	σ= 10 µs	σ= 30 µs
50	34.15µs	102.89µs	3.69 µs	11.66 µs	1.32µs	3.61µs

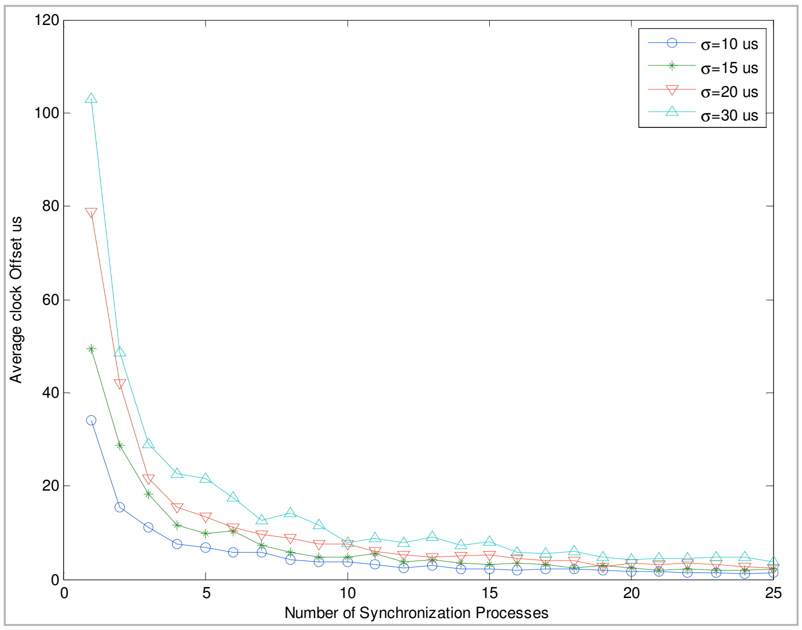

Fig. 11: Average clock offset on different receive delay difference in standard deviation for 50 nodes.

The frequency accuracy performance is evaluated by measuring the average clock skew with a number of synchronization processes for σ = 10 µs, *15* µs, *20* µs, and σ =30 µs, as shown in Figure 12. In a worst case scenario, when σ is 30us and number of synchronization processes are 25, and thenclock skew is significantly reduced from 7 to nearly 0.35 parts per million (ppm). This is how the ultimate aim of obtaining clock skew is achieved with the minimization of frequency error.

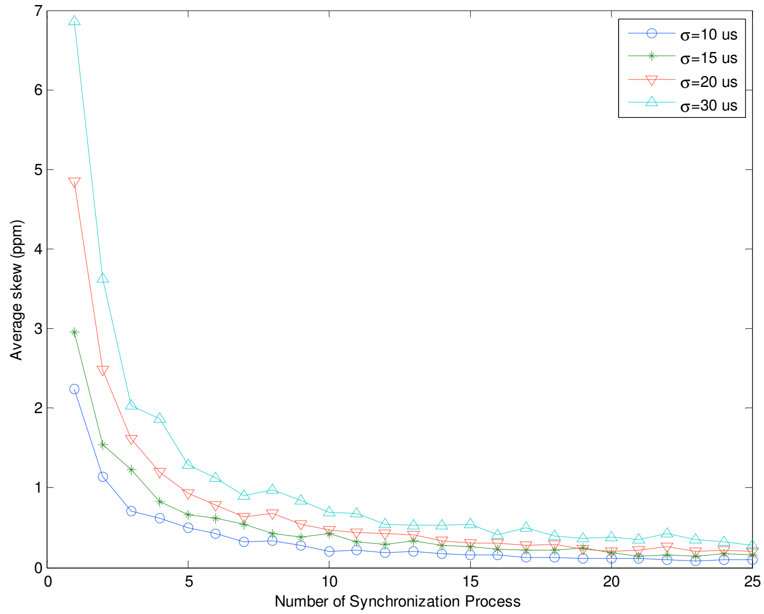

Fig. 12: Average clock skew on different receive delay difference in standard deviation for 50 nodes

6. CONCLUSION

The proposed synchronization scheme aims to synchronize the fBS neighbor networks. The proposed scheme differs from previously developed IEEE 1588, RBS, and even receiver-receiver schemes in the sense of forming clusters among the random number of fBS nodes and applying hybrid (two ways and one way) messaging system to entire synchronization scheme. Proposed synchronization scheme is cluster based and can be applied for a large number of femtocell base stations (fBS) nodes in femtocell network. The proposed scheme acheived better synchronization accuracy than the previous MS assisted synchronization strategy.

REFERENCES

[1] Hasan, M. K. Saeed, R. A. Aisha-Hassan A. H. “Femtocell Network Synchronization.”*Femtocell communications and technologies: Business opportunities and deployment challarges*, Global Publications (USA), 2011.

[2] Hasan M. K., Aisha-Hassan A. H., Rashid A. Saeed, Shayta Islam, Othman O. Khalifa An “Investigation of Femtocell Network Synchrunixation.” *Presented at IEEE Conference on Open Systems,*ICOS2 2011. Doi: l0.l109/ICOS.20I 15079232.

[3] Sungwon L. “An Enhanced IEEE 1588 Tirne Syrchronization Algoithm for Asymmetic Cammunication Link using Block Burst Transmission.” *IEEE communicalions letters*, 2.9 (2008).

[4] Hwang S. L., Jangho Y., Jaeki L. “Muhi-hop Based Nework Sytchronization Scheme for Femtocell Systems.” *IF,EE 2fth International Symposium Personal, Indoor and Mobile Radio Communications*, 2009.

[5] Mills D. L. “Internet Time Synchronization: The Network Time Protocol.” *IEEE Transaction on Communications*, 10(1991): 1482-93.

[6] Mills D., Delaware U., Martin J., Burbank J., & Kasch W. "Network Time Protocol Version 4: Protocol and Algorithms Specification." *Internet Engineering Task Force @TD.* Accessed January 1, 2011 from http:l/tools.ief.org/htmUrfc5905.

[7] Peng J., Li Z'., Mclernon D., & Jibo W. . "A Novel Receiver-Receiver Time Synchronization Scheme for Femtocells." *IEEE Wireless Communication Systems (ISWCS)*, 2010.

[8] Peng J., Li Z., M:cLemon D . "MS-assisted Receiver-Receiver Time Synchronization Scheme for Femtocell s." *IEEE Conference on Vehicular Technology*, 2011.

[9] Hani M., Steven D. B., & Tommy S. "A New Distributed Approach for Achieving Clock Synchronization in Heterogeneous Networks." *GLOBECOM 2011- Next Generation Networking Symposium,* 2011. doi: 1 0. 1 1 09/GLOCOM.201 1.6 1 33859.

[10] Xiaoyan 2., Zhijian & Houjun W. 201 I . "Novel Method of Time Synchronization based on IEEE 1588." *JDCTA: International Journal of Digital Content Technology and its Applications*, 5.7 : 275 -82

[11] Wada T., Saitou, N., Hara T., & Okada M., "Frame synchronization among Base Stations for TDD system." *4th International Symposium on Communications, Control and Signal Processing (ISCCSP)*, (2010): 14. doi: 1 0. 1 I 09/[SCCSP.20r 0.546347 6.