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Femtocell Network Time Synchronization Protocols and Schemes

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Abstract: The femtocell network allows connecting to cellular network through broadband connection. In femtocell, time with network synchronization becomes a critical issue at present. Synchronization is a process which is required in the femtocell network due to the shortcomings of centralized coordination between a number of femtocell Base Station (fBS) and clock synchronization server. Time synchronization procedure allows exchanging message that contains timestamp and delay measurement. There are several time synchronization protocols and algorithms based on precision which are Network Time Protocol (NTP), Simple Network Time Protocol (SNTP), IEEE 1588 Timing Protocol, enhancement of IEEE 1588 timing and receiver-receiver synchronization scheme. In this study, we investigated some of the time synchronization protocols and schemes for femtocell network. In addition, we proposed intra-cluster synchronization scheme to minimize the clock offset and skew for better synchronization accuracy. The proposed scheme is able to perform precise synchronization for clock offset and clock skew than the existing receiver-receiver synchronization scheme.

Key words: Femtocell network, IEEE 1588, NTP, time synchronization

INTRODUCTION

The recent advancement of femtocell technology has emerged in cellular wireless networks and rapidly taken its place in the cellular industry. The principle of femtocell is to reduce the network operation cost as well as extend indoor coverage, which is also considered as a promising path way toward the Fixed Mobile Convergence (FMC) goal. Femtocell intends to serve a small number of users, i.e. four users with the coverage of approximate thirty meter square similar to existing WiFi access points. In contrast with micro and macro cellular network, the femtocell network allows connecting to cellular network through broadband connection, which is unique in nature. In addition, femtocell Base Station (fBS) is capable of communicating with the macro Base Station (mBS) for controlling purposes. Time synchronization plays a vital role in femtocell neighbor networks (Peng *et al*., 2010). Moreover, synchronization is a process which is required in the femtocell network due to the shortcomings of centralized coordination between a number of fBSs and clock synchronization server. Therefore, a carrier offset and frequency errors (skew) are introduced in the fBS networks that increase time delay. In addition, it is highly essential to synchronize fBS neighbor networks with the purpose of minimizing message overhead and ensuring a tolerable carrier offset. Since this technology has not yet come within the reach of attaining a good level of synchronization accuracy, researchers have put forward some advanced algorithms over the recent years (Mills *et al*., 2010; Sungwon, 2008; Wada *et al*., 2010; Peng *et al*., 2010; Jangho *et al*., 2009; Hasan *et al*., 2011).

In this study, we investigated some of the time synchronization protocols and schemes for femtocell network. In addition, we proposed intra-cluster synchronization scheme to minimize the clock offset and skew for better synchronization accuracy. The proposed scheme is able to perform precise synchronization for clock offset and clock skew than the existing receiver-receiver synchronization scheme.

MATERIALS AND METHODS

Femtocells are required to meet minimum time and frequency synchronization requirements imposed by

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Table 1: Time and frequency requirements in femtocell network (Pesyna *et al*., 2011)

Standard of femtocell	Time	Frequency accuracy
CDMA 200010	10μs	0.05 ppm
GSM	NA	0.05 ppm
WiMAX	1 μs (TDD)	2.00 ppm
LTE	3 μs (TDD)	250.00 ppb
WCDMA	2.5 μs (TDD)	0.05ppm
TD-SCDMA	2.5 μs	100.00 ppb

cellular standards. Time synchronization requirements are necessary to avoid interference and negotiate seamless handovers in synchronized networks, particularly in Time-Division Duplex (TDD) networks. Frequency synchronization requirements are necessary to maintain frequency alignment with the macrocells to avoid spectrum interference, particularly in Frequency-Division Duplex (FDD) networks (Pesyna *et al*., 2011). Table 1 highlights the time and frequency synchronization requirements imposed by various third Generation (3G) and fourth Generation (4G) cellular standards.

The Worldwide interoperability for Microwave Access (WiMAX), Long Term Evolution (LTE), Wideband Code Division Multiple Access (WCDMA) and Time Division Synchronous Code Division Multiple Access (TD-SCDMA) standards are particularly strict in their time requirements whereas the Code Division Multiple Access (CDMA2000), Global System for Mobile communications (GSM) and TD-SCDMA standards are particularly strict in their frequency requirements (Pesyna *et al*., 2011).

Time synchronization procedure allows exchanging message that contains time stamp and delay measurement. There are several time synchronization protocols and algorithms based on precision which are Network Time Protocol (NTP), Simple Network Time Protocol (SNTP), IEEE 1588 Timing Protocol, enhancement of IEEE 1588 timing and receiver-receiver synchronization scheme. A comprehensive discussion on NTP and IEEE 1588 time synchronization protocols with some approaches is given in the following.

Network Time Protocol (NTP): NTP is a protocol for the purpose of synchronizing the clocks over packet-switched networks (Mills *et al*., 2010). It is designed mainly in the direction of reducing the effects of variable latency through jitter buffer. NTP aims to synchronize timekeeping among several distributed time servers as well as clients. It is structured based on the Internet Protocol (IP) and User Datagram Protocol (UDP) that offers a connectionless transport technique. Nevertheless, it can be adjustable to other protocol suites. NTP has been developed from the time protocol and the Internet Control Message Protocol (ICMP) timestamp message which is predominantly designed in order to ensure accuracy and robustness, while used over usual internet pathways. The service model is founded on a returnable time design that is measured clock offsets depended and eliminates the need of reliable message delivery. A self-organized, hierarchical-master-slave arrangement is used by synchronization where a minimum-weight spanning tree determines the synchronization paths.

IEEE 1588 timing protocol: IEEE 1588 Version 1 (V1) specification points to the fact that the best Precision Time Protocol (PTP) performance can be obtained through reducing the number of nodes between the clock source and the slave devices. Synchronization (SYNC) message rates are relatively faster than IEEE 1588 Version 1. IEEE 1588 Version 2 (V2) identifies an extensive range of mean SYNC message rates which allows much larger rates than 1000 messages per second. Conversely, the majority of the systems are likely to use mean SYNC message rates much less than IEEE 1588 Version 2 to minimize network traffic as well as optimize the time of network loading with improving the performance of synchronization. However, faster SYNC message rates are essential for telecommunications, residential Ethernet and different control applications. Figure 1 illustrates a typical IEEE 1588 synchronization scenario.

Additionally, IEEE 1588 is addressed as a master-slave synchronization protocol that includes two main operations (Andre and Dominik, 2007) as shown in Fig. 2. At the beginning, a master-slave hierarchy of clocks is established in which the entire slave clock synchronizes to its master clock. Secondly, one allows making only the required information available for slave clocks to carry out this synchronization. This synchronization protocol applies stamping SYNC and DELAY_REQ messages. Synchronization (SYNC) message is sent only once in every 2 sec via master clock. Master clock measures the exact time (t_{m1}) at which the SYNC message is sent. The time when a slave clock receives the SYNC message, it instantly measures and stores the reception time Ts.1. Subsequent to that, a FOLLOW_UP message is sent by master clock which contains the exact value of the time stamp that is indicated as t_{m1}. Meanwhile, DELAY_REQ messages are sent by the slave clock periodically and stored their transmission time with a timestamp Ts.2. As soon as the master clock receives the DELAY_REQ message, in reply, it sends a DELAY_RESP message, which includes the time stamp t_{m2}.

The slave clock computes the downlink transmission delay δ_1 and the packet transmission delay δ_2 from these timestamps which are expressed as:

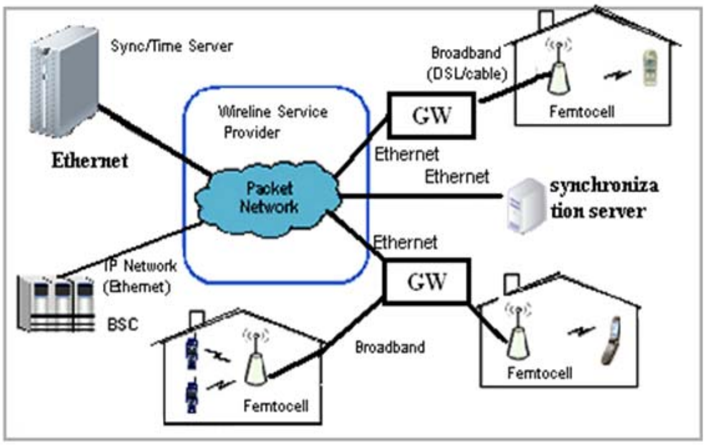

Fig. 1: IEEE-1588 in a femtocell base station

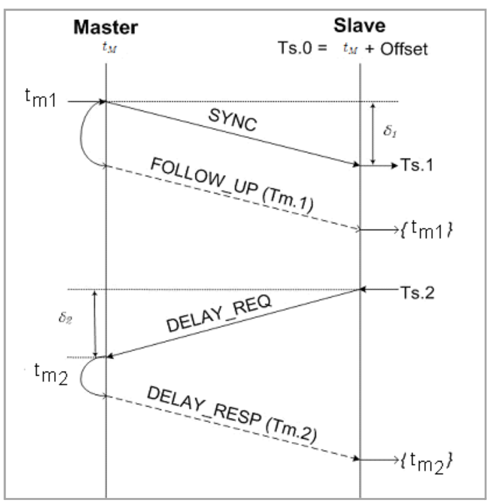

Fig. 2: Master slave synchronization protocol (Andre and Dominik, 2007)

$$\delta_1 = Ts.1 - t_{m1} \quad (1)$$

$$\delta_2 = t_{m2} - Ts.2 \quad (2)$$

From Eq. (1) and (2), a projected one-way delay δ_w is calculated by the slave clock which is in Eq. (3) and the offset of the slave clock is computed with regard to the master clock which shows in Eq. (4). The expressions are:

$$\delta_w = \frac{\delta_1 + \delta_2}{2} \quad (3)$$

and

$$Offset = \delta_2 - \frac{\delta_1 + \delta_2}{2} = \frac{\delta_2 - \delta_1}{2} \quad (4)$$

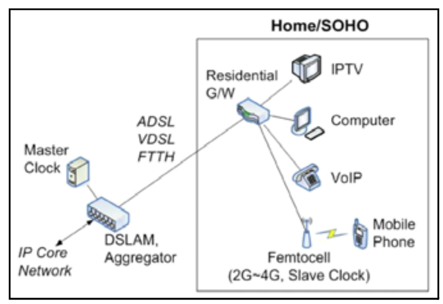

Fig. 3: IEEE 1588 for femtocell network environment (Sungwon, 2008)

The slave clock regulates it's time to reduce the offset value, thus facilitating the synchronization with the master clock. The two-way timing messages exchange allows correcting the exact transmission time between the master clock and slave nodes. In contrast, if the exact transmission time is not corrected, then this time might emerge as an offset of two clocks. Conversely, in femtocell network environments as depicted in Fig. 3, the communication link for the femtocell cannot be assumed as a symmetric link for every cases. If the communication link for the femtocell is asymmetric, δ_1 and δ_2 in Eq. (3) are different (Sungwon, 2008). Accordingly, δ_w is just a mean transmission delay for downlink and uplink. Consequently, offset value cannot be zero and it means that the permanent time synchronization error between the master clock and the slave clock which is unable to determine the error.

Synchronization schemes: A novel method of time synchronization is proposed by (Xiaoyan *et al*., 2011). The proposed method updates the slave clock model in ti

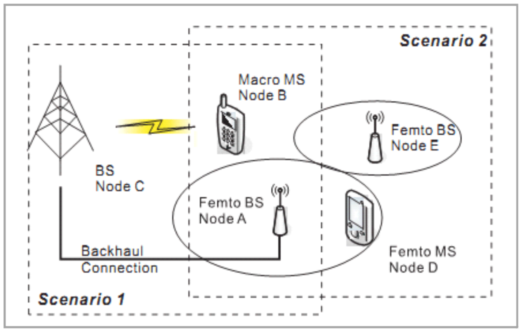

Fig. 4: The two femtocell synchronization scenarios (Peng *et al*., 2010)

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. By combining drift compensation and asymmetric communication, the precision of time synchronization will significantly be improved. The proposed scheme developed one clock model since, time synchronization minimizes the difference between the time on slave clock and the time on master clock. Hence, the difference is calibrated as offset of slave clock. As the clock model in Eq. (5):

$$Offset = T_m(t') - T_s(t') = \varepsilon \cdot t' + b \tag{5}$$

where, T_m is the time on master clock, T_s is the time on slave clock, ε indicates the drift of slave clock relative to the master clock and b is the initial offset between slave clock and master clock at the reference time $t' = 0$.

It can be seen that due to the existence of drift, the difference increases with the reference time t′. In time synchronization, if consider calibrating offset, though the time on slave clock achieve high precision at the moment of calibration, the increase speed of the difference is not reduced and drift is variable in such of environment. On the other hand, the duration between each calibration is 2 sec, drift assumed constant in the little period of time. Drift can compensate in time synchronization to recover the difference.

Jangho *et al*. (2009) 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 does not need iterations for full network synchronization. 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. However, if the distance between the synchronizing femto BS and the reference is short enough, the hop count need not to be increased.

Receiver-receiver synchronization scheme proposed for fBS neighbor nodes in order to get the synchronization accuracy (Peng *et al*., 2010). This scheme followed the Reference Broadcast Synchronization (RBS) to reduce the clocks offset and skews by using the MS and mBS. In addition, it is also found that the receiver-receiver synchronization scenarios where two fBS nodes considered, node A and E. Figure 4 shows that the scheme is fully depends on Mobile Station and mBS where a reference node, node A is used to synchronize the fBS nodes which is considered in order to achieve synchronization accuracy through mobile station assistance synchronization strategy.

Figure 5 shows that the scheme is fully depend on Mobile Station and mBS where a reference node is used

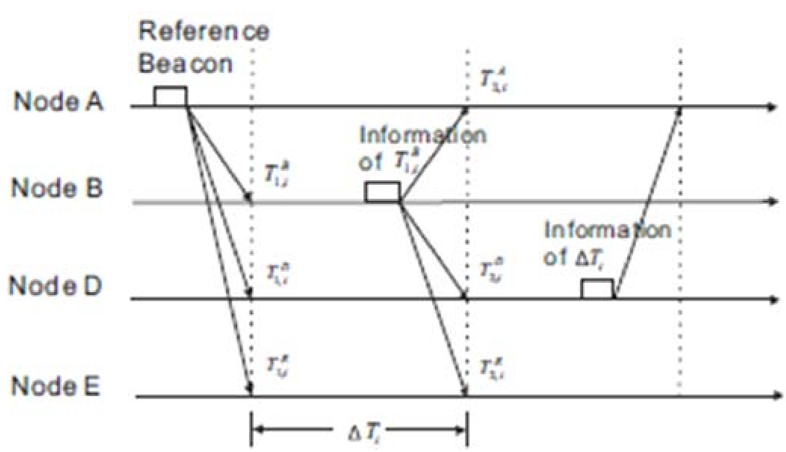

Fig. 5: Rceiver-receiver synchronization scheme (Peng *et al*., 2010)

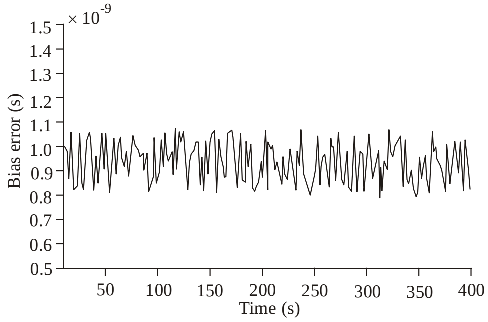

Fig. 6: The bias error calculated without drift compensation (Xiaoyan *et al*., 2011)

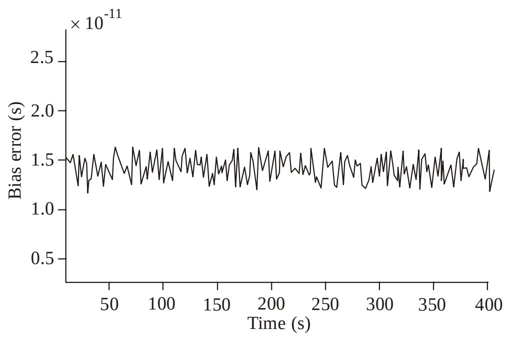

Fig. 7: The bias error calculated with drift calibration (Xiaoyan *et al* ., 2011)

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.

However, a number of beacon messages are flooded in the entire network which cause overhead for a large number of fBS nodes. Some investigations and modifications are required in this scheme in order to get proper synchronization through minimizing the clocks offsets and optimizing the synchronization accuracy.

The bias error without drift compensation illustrated in Fig. 6 which shows, the average and maximal Bisa Error are 9.32×10^{-10} and 1.07×10^{-9} s, respectively. Furthermore, the bias error with drift compensation depicted in Fig. 7 where it showed the average and maximal Bisa Error are 1.45×10^{-11} and 1.68×10^{-11} s, respectively (Xiaoyan *et al*., 2011).

The average bias error of the time on slave clock as a function of the asymmetric ratio is illustrated in Fig. 8.

It can be summed up from the results analysis of Xiaoyan *et al*. (2011) method of time synchronization using IEEE 1588 that this method updates the slave clock model in time synchronization, through implemented messages exchange. Through compensating clock drift, it can be possible to increase speed of the difference

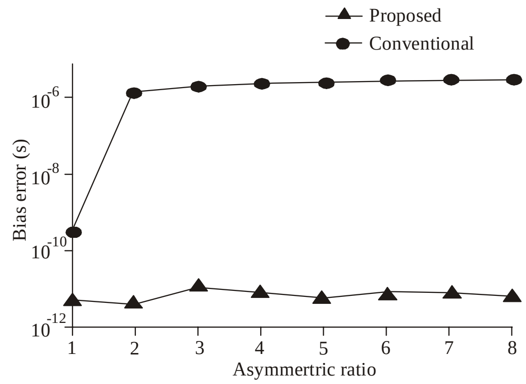

Fig. 8: Average bias error in time synchronization scheme (Xiaoyan *et al*., 2011)

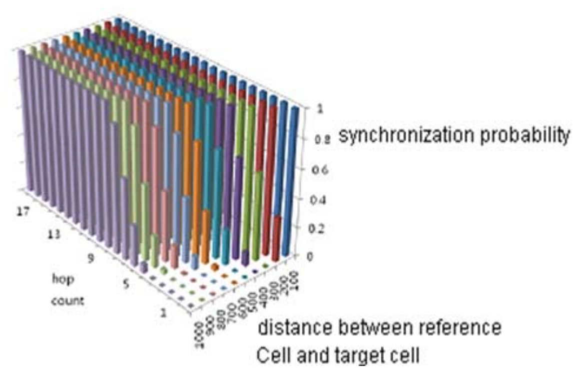

Fig. 9: Performance of the multi-hop based network synchronization (Jangho *et al*., 2009)

between the time on slave clock and the time on master clock which is reduced. In addition, 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 as shown in Fig. 9.

RESULTS AND DISCUSSION

Proposed intra-cluster scheme: The proposed scheme can be categorized in two steps which involve clustering process and intra-cluster synchronization. Cluster Head (CH) selection is the initial process in clustering scheme that is performed based on time and distance. In the intra-cluster synchronization, fBS node sends beacon broadcast message to another fBS node and compare their clock time in order to establish the time synchronization between cluster heads and cluster members. Ultimately, linear least square method is applied to attain a high level of precision. The proposed synchronization scheme targets fBSs in an environment where fBSs are located in unplanned and uncoordinated way.

ID	μ (Sync)	Distance	Multi-hop

Fig. 10: SYNC message structure

In the beginning of clustering process among the large number of fBS nodes, CHs will be elected. The ultimate process which is inter-cluster synchronization will be performed within the clusters after selecting the CH, Cluster Member (CM) and Intermediate Node (IN). Once the CH election is complete, then clusters will be formed by the elected CHs. As a continuation of this process, the intra-cluster synchronization scheme will be approached for all CMs. This process is followed by the proceeding of IN selection scheme.

The proposed clustering techniques are classified based on two criteria:

- Fuzzy Relevance Time (FRT)
- Distance and average transmission range.

The SYNC message structure is depicted in Fig. 10.

The parameters of the SYNC message are explained as follows:

Identifier (ID): ID is assigned for distinguishing each node from other nodes during the selection of cluster head.

Fuzzy Relevance Time (FRT) (μ): FRT is a fuzzy value $\mu(0 \le \mu \le 1)$ determined by available time and distance of neighboring nodes. Here is μ use for the parameter of sync time. In order to ease the computational difficulty, μ is assumed as aset of fuzzy value of time between 0 and 1, which ranges in {0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1}. This fuzzy time is assumed in microsecond range. FRT of a node represents the local time provided by neighbor nodes in the network. The proposed scheme, selects the cluster head based on the FRT and the distance between nodes. The scheme performs clustering based on parameters described above and selects the CH for efficient clustering.

For n nodes of $N = \mu\ \{X_1, X_2, X_3, \ldots.(X_n)\}$, $\mu\ (X_i)$ is defined by the following equation:

$$\mu = \{\mu(X_1), \mu(X_2)\ \mu(X_3)\ldots\mu(X_n)\ (1 \le i \le 1) \quad (6)$$

where, X_i is a member node for clustering in the network and $\mu(X_i)$ is a membership function. The FRT for node X_i is $FRT(X_i)$, which can be defined by the following equation:

$$FRT(X_i) = \mu(X_i) \quad (7)$$

Distance: In case of a large number of femtocell networks, distance is considered as an important parameter for selecting CH and creating clusters. Since the fBS distance is 20-30 m, the distance between the CH i and member node j, $d_{x_{i x_j}}$ is assumed to be 30 m for selecting the CH and clustering process.

Multi-hop: Multi-hops controls the management and generation of the 1-hop cluster and 2-hop cluster according to fuzzy relevance time. In large scale networks, CHs create clusters for multi-hop. Thus, the multi-hops adjustment regulates the size of clusters according to the network size.

Moreover, in Reference Broadcast Synchronization (RBS), synchronization messages are broadcasted from a reference node which will result in message flooding and ultimate decreasing of the network throughput (Jeremy *et al*., 2002). However, through proposed clustering process, it is possible to decrease the number of flooded message from network by divide the network into clusters. In this way, the entire femtocell network will

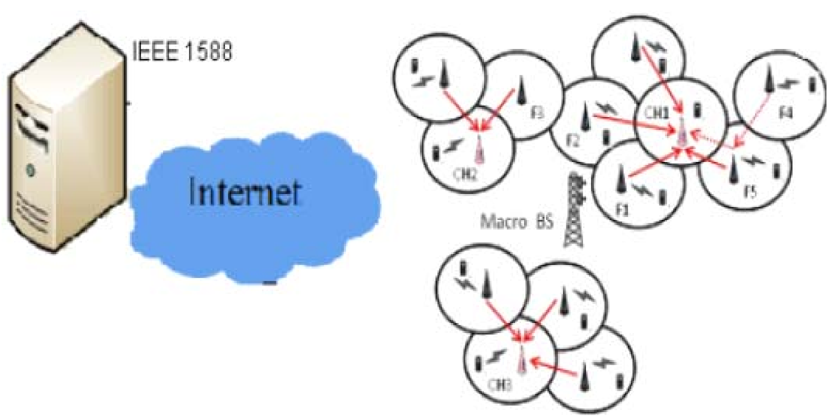

Fig. 11: Femtocell neighbour network cluster model

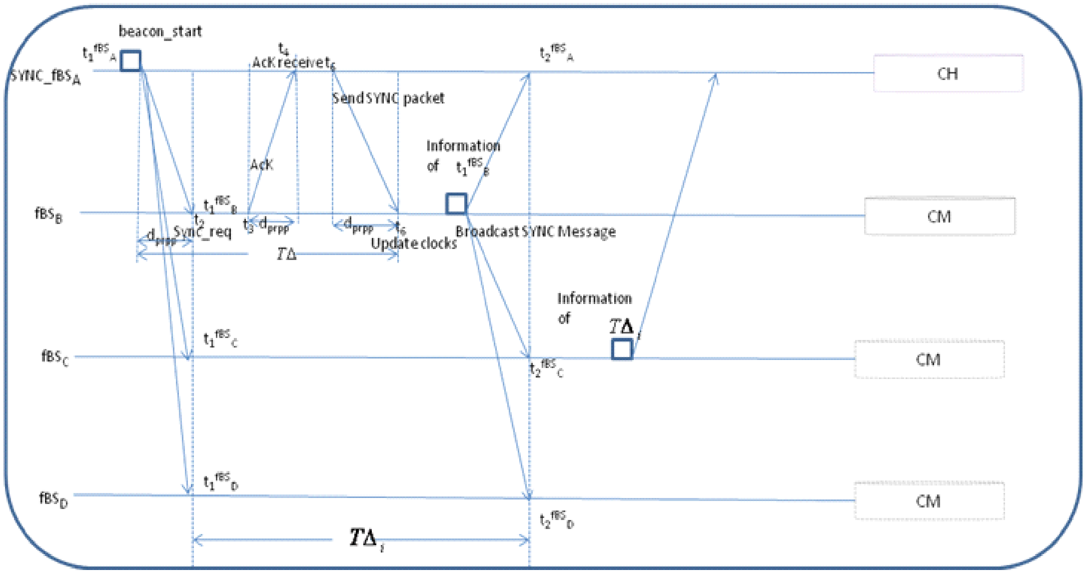

Fig. 12: Proposed intra-cluster synchronization scheme

Step 1: Initially, CH starts the i[th] synchronization process by broadcasting a sync message inside the cluster.

Step 2: After receiving this sync message from the synchronized node, all the CM records the message arrival time which are $T_{n,\ i}^{Node\ j}$, and θ_{Skew}^{ij}.

Step 3: CM node j broadcasts the sync message including the message arrival time from the previously broadcasted message.

Step 4: Inside the cluster neighboring nodes', local clocks are exchanged and compared with the new clocks of synchronizednodes to calculate the offset and skew for node i and j.

Step 5: Apply 'M' number of synchronization process.

Fig. 13: Intra-cluster synchronization scheme steps

enhance the level of performance of the network through reducing the overhead. Figure 11 shows the fBS network cluster model.

In the proposed scheme, once the clustering is accomplished, the intra-cluster clock synchronization scheme will be applied for the entire cluster members to synchronize the clocks which will lead to the establishment of a better synchronized network.

Intra-cluster synchronization scheme is depicted in Fig. 12.

Intra-cluster synchronization scheme steps are shown in Fig. 13.

CONCLUSION

In this study, we investigated the time synchronization protocols and schemes for femtocell network. In addition, we proposed intra-cluster synchronization scheme to minimize the clock offset and skew for better synchronization accuracy in femtocell network. The main contribution of this study is in reducing the clock offset and skews through the proposed scheme and achieving ultimately precise synchronization. The proposed scheme differs from previously developed IEEE 1588 and even receiver-receiver synchronization scheme 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 intra-cluster synchronization schemes. The scheme involves updating and synchronizing the clocks through exchanging SYNC messages within the entire network. The proposed scheme is cluster based and can be applied for a large number of fBS nodes in femtocell network. As a future study, we plan to carry out a performance evaluation study in order to justify the outcome of the proposed scheme.

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