A Velocity-based Bicasting Handover Scheme for 4G Mobile Systems

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***Abstract*—We propose a velocity-based bicasting handover scheme to efficiently utilize backhaul network resources in Fourth-generation (4G) mobile systems. The conventional bicasting scheme makes all potential target base stations hold the user data, thus it can achieve seamless connectivity by minimizing the packet fluctuation delay caused by handover. This scheme, however, leads to an aggressive consumption of resources at the backhaul network. When this scheme is widely adopted for real-time services and the demand for these services increase, the amount of backhaul network resources consumed due to bicasting will also increase tremendously. Therefore, we proposed a velocity-based bicasting scheme which reduces the bicasting time and thus, improves the backhaul network resource utilization. Our scheme uses a novel concept of bicasting threshold determined on the basis of specific mobile speed groups. The simulation results prove the efficiency of our scheme in overcoming the aggressive resource consumption at the backhaul network.**

I. Introduction

Next generation wireless systems envision a future with better communication infrastructure in terms of both quantity and quality. It is expected that various real-time services requiring high data rate in varied mobility environments with short delay will be one of the main applications of Fourth Generation (4G) wireless communication systems. [1] introduces various real-time services requiring high data rate and very short delay. For example, a video conference or a real-time gaming service requires a data rate of 1–20 Mbps with highly interactive delay of less than 20-ms and a geographic real time datacast service through real-time video streaming demands a data rate of 2–5 Mbps within a delay of 20-ms [1].

In order to support high quality-of-service (QoS) for real-time services, the packet transmission delay fluctuations should be minimized. In case of an intra-system handover, the packet delay fluctuations for real-time video streams are desired to be 30-ms or less [2]. A longer delay or brief disruption in the transfer rate of the application layer becomes noticeable by the user due to latency in delivering the real-time packets during handovers for example, causing serious playback issues at the receiving end. A buffer management mechanism is offered at the receiver's application layer to reduce this network induced jitter. For a disruption-free service, the amount of data in the receiver's application layer buffer should be above a certain threshold. If the network can not acquire more packets and the packets in the buffer fall below this threshold, the QoS for the real-time services will be deteriorated. The MAC layer has no information regarding the status of application layer buffer. This means that it can not determine when the buffer is in a underflow status. Therefore, to offer a seamless flow of service at the application layer and avoid underflow buffer conditions, it is necessary to minimize the packet delay fluctuations at the MAC layer.

The 3rd Generation Partnership Project Long-Term-Evolution (3GPP LTE) system recommends a layer 2 mechanism called data bi-casting scheme for improving handover interruption time caused by cell switching in order to support QoS for real-time services. A cell switching set (CSS) comprising of possible target base stations (BS) is formed, and the same copy of down-link user data is made available to all the BSs belonging to this CSS [3] [4] [5]. The idea here is to make the data available in all the potential target cells at all times to minimize handover delay. However, the question of indefinite accumulation of user data in a cell is not properly dealt. The only suggestion made by the 3GPP LTE system is to use an automatic discard timer which can discard the non-transmitted user data in the buffer of the cell after some time-out [4].

In this paper, we disagree on the efficiency of the discard timer in reducing the amount of resources consumed by bi-casting execution at the backhaul network. In case of numerous users looking for high data rate services and respective handover executions within a system, the data bi-casting scheme would certainly, generate a lot of load on the backhaul network. [6] addresses the necessity to make an efficient use of backhaul network resources. It states as the backhaul network could be a scarce resource, it is important to utilize the backhaul network resources in an efficient manner. Moreover, the load on the backhaul network associated with signaling and state transfers during a handover is desired to be low. Therefore, a scheme, which minimizes the amount of resources consumed at the backhaul network by user data bi-casting scheme is needed in 4G wireless systems.

The goal of this paper is to reduce the amount of resources consumed at the backhaul network by reducing the bi-casting time. In the original scheme, bi-casting time is usually determined by the signal-to-noise-ratio (SINR) value. Since the SINR value for a user fluctuates abruptly with velocity, it

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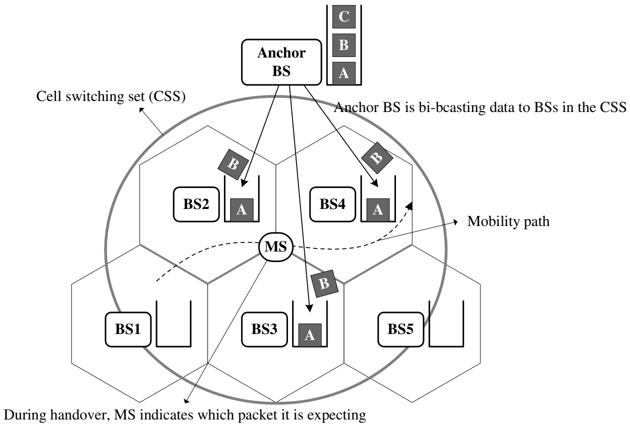

Fig. 1. User data bi-casting to all the BSs in the CSS

is hard to determine a specific point to start data bi-casting. Moreover, for a user moving with high velocity, the SINR from the neighboring cell gets detected and shows an abrupt increase, while for a low velocity user, the increase in the signal strength is comparatively slower. So, it is anticipated that the consumption of network resources can be definitively reduced by controlling the bi-casting time with velocity. Therefore, we propose a velocity-based bi-casting threshold scheme, which reduces the user data bi-casting time, and eventually enhances the utilization of backhaul network resources.

The remainder of this paper is organized as follows: Section II presents the system model and the problem definition. We describe our proposed velocity based bi-casting scheme in Section III. Section IV shows the performance results based on which we prove that our scheme is efficient in reducing the backhaul network load. Finally, we conclude this paper in Section V.

II. System Model and Problem Definition

The system architecture proposed in this paper is similar to the one proposed for Extended-UMTS Terrestrial Radio Access Network (E-UTRAN) [7]. It is a hierarchical system model consisting of Anchor BS(s) responsible for the transmission of IP packets to the BSs. Anchor BS is also responsible for continuous pre-configuration and management of all the BSs and a full connectivity link between the Anchor BS and the BSs is allowed over the backhaul network.

The 3GPP LTE system referred to as one of the main candidates of 4G wireless system, complies with the transmission of data to the mobile station (MS) from one BS at a time. It, therefore, becomes necessary to have a fast and robust ability to change the serving BS with minimal delay and signaling overhead. As a solution to these requirements, fast cell switching scheme, which follows a hard handover operation mechanism is proposed [4]. In the scheme, a cell switching set (CSS) is formed by selecting the potential target BSs, which can maximize the user throughput and is managed by continuously adding or removing a cell based on the downlink SINR. This SINR used in the determination of BS selection is obtained by averaging the periodically measured instantaneous SINR values reported by the MS and is referred to as the filtered SINR. For MS to be able to perform a handover seamlessly, it is essential that the packet delay fluctuations be minimized. Therefore, user data bi-casting [3] [4] [5], which enables data duplication through the serving BS and potential target BSs has been proposed in the literature. The key idea of user data bi-casting scheme is to supply the same copy of down-link user data to all the BSs belonging to the same CSS at all times. This is done to make the user data available in all the potential target BSs, ready for transmission ahead of time, and perpetually before the handover execution to minimize delay.

Fig. 1 illustrates the user data bi-casting scheme. Based on the SINR measurements provided by the active MS, a CSS containing BS2, BS3, and BS4 exists. The anchor BS bi-casts the same copy of downlink user data to all the BSs in the CSS which in turn keep the user data ready for transmission in their respective buffers. As soon as the handover is executed, the MS indicates the packet that it is expecting to the target BS and forms a seamless connection receiving the data held in the target BS before handover.

Again, as shown in Fig. 1, for the MS moving on the depicted mobility path, although the user data is only transmitted over-the-air from BS2, BS4 and BS3 fall victim to unnecessary accumulation of data packets. This eventually leads to the indefinite accumulation of user data in the respective cell buffers. A discard timer, which can automatically discard the non-transmitted user data in a cell after some time-out is recommended as the possible way to deal with the data accumulation issue by the 3GPP LTE system. However, this is not a possible solution to the excessive consumption of backhaul resources as it just discards the bi-casted data in the buffers of the BSs, instead of making an efficient attempt to acquire only the required data.

In this paper, we propose that the backhaul network utilization can be efficiently achieved by minimizing the bi-casting time as it has a direct impact on the usage of network resources. If $SINR_F$ and Th respectively denote the filtered SINR from a BS and bi-casting threshold value, our problem is mathematically defined as

$$\arg\min_{Th_i \in M} \{Th_i | Th_i < SINR_F)\} \tag{1}$$

where i is the index associated with each threshold value and M is a set of all the threshold values. Therefore, our aim is to find an optimal threshold value initiating the execution of bi-casting in order to minimize the bi-casting time.

III. Proposed Velocity-based Bi-casting Scheme

In this section, we describe our velocity-based bi-casting scheme. As stated above, bi-casting is executed based on the SINR value. As soon as the received SINR from a potential target BS reaches a threshold, the BS gets added to the CSS, and user data bi-casting to this newly added BS takes place.

However, we argue that this is not an efficient way to start bi-casting. For a high velocity user, it might be appropriate to start bi-casting at the earliest in order to meet the seamless handover requirements, but for a user with medium or low velocity an early start of bi-casting consumes much resources at the backhaul network. Therefore, we define a bi-casting threshold based on velocity with an aim to enhance the backhaul network resource utilization in 4G wireless systems.

In order to estimate the velocity of a mobile user, a lot of schemes have been proposed in the literature [8][9]. Most of these use the statistics of the envelope of the received SINR. Of the proposed methods, zero crossing ratio (ZCR) method is the most popular one due to its simplicity and good performance [10]. The ZCR of the in-phase or quadrature component of the received SINR estimates the velocity of the MS, v_e as follows:

$$v_e = \frac{\lambda}{\sqrt{2}} N_I(0) = \frac{\lambda}{\sqrt{2}} N_Q(0) \tag{2}$$

where $N_I(0)$ and $N_Q(0)$ are the number of zero crossings of the in-phase and quadrature components of the received signal, respectively, and λ is the carrier wavelength [9]. For our algorithm to be implemented in a practical scenario, we can use this velocity estimation technique.

We state that it is not practical to define a threshold value for each and every velocity parameter. Instead it would be better in terms of a practical scenario to group the similar velocities into a group and determine bi-casting threshold values for these groups. For example, consider Th_i and Th_j to be the respective bi-casting threshold values for velocities v_i and v_j. Then, given the threshold Th_i, we define the following condition:

$$|Th_i - Th_j| < \delta, \tag{3}$$

where δ is a criterion for grouping. When the above condition holds, for a fairly small value of δ, $Th_i = Th_j$. Therefore, v_i and v_j form a group. Also, when $|Th_i - Th_{j+1}| > \delta$, v_{j+1} groups itself into a different speed group. This accounts for the fact that for similar velocities, a representative bi-casting threshold value could be determined. In this paper we assume that the value associated with δ is 1 dB. Based on the above arguments, we model three mobile speed groups, namely, pedestrian ($\sim$ 15 km/h), vehicle (15 km/h $\sim$ 90 km/h) and express bus/train (90 km/h $\sim$) for urban mobility scenario. These groups are formed in reference to the mobility support mentioned by 3GPP E-UTRAN [7]. And, for sub-urban scenario, high speed mobile groups with velocities ranging from 120 km/h to 200 m/h, 200 km/h to 250 km/h and 250 km/h above are formed. Section 4 presents a brief description on the mobile speed groups.

In our proposed scheme, bi-casting has different execution time depending upon the mobile speed group in which the velocity parameter of the MS lies. Apparently, it would be best in terms of backhaul network resource enhancement to execute bi-casting at the execution of handover. This means that an ideal time for bi-casting would be handover execution time.

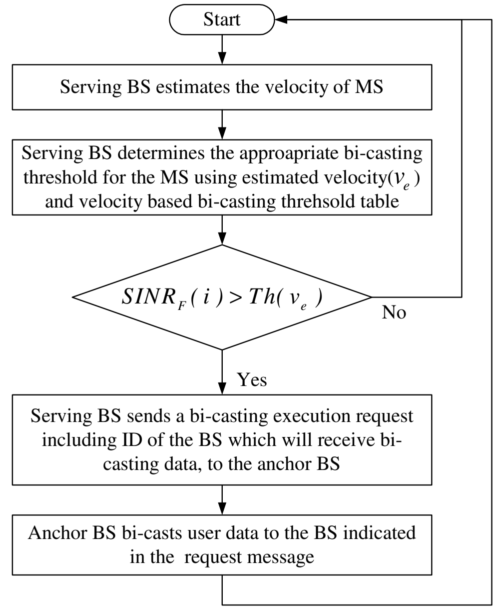

Fig. 2. Procedure of velocity-based bi-casting scheme.

However, this is a practically impossible approach, especially for a high velocity user. Therefore, we consider signaling overhead in finding the appropriate bi-casting threshold values for each mobile speed group. If $T1$ is the time taken by serving BS to estimate the velocity of MS and to have SINR values of all the other BSs belonging to CSS, $T2$ is the time taken by the serving BS to recognize the BSs which will receive bi-casting data and inform this to anchor BS, and $T3$ is the time taken by the anchor BS to prepare for bi-casting to the newly recognized BSs, we consider that the total time to prepare for bi-casting is

$$T_1 + T_2 + T_3 < \alpha \tag{4}$$

That is, the target BS receives user data bi-casting from the anchor BS, α seconds before the execution of handover.

Fig. 2 gives a block diagram representation of the proposed scheme. For a moving MS, the serving BS estimates the velocity of the MS using the velocity estimation calculated in Equation (2). The estimated velocity, v_e, is matched to the appropriate bi-casting threshold value given in Table 2. For instance, if a user's estimated velocity is 40 km/h, using Table 2, we can assign a bi-casting threshold of –6 dB to this user. This velocity based bi-casting threshold value is denoted as $Th(v_e)$. The filtered SINR value, $SINR_F$, from all the base stations contained in the CSS is determined. If i represents the ID of BSs, then for all $i \in$ CSS, it is checked whether the following condition

$$SINR_F(i) > Th(v_e) \tag{5}$$

holds. If it does, the serving BS sends to the anchor BS, a bi-casting execution request including the IDs of the BSs to which user data bi-casting should be offered. The procedure

TABLE I
SIMULATION ENVIRONMENT

Items	Description
Network topology	19 cells
BS-to-BS distance	1 km (Urban), 2.5 km (Sub-urban)
Propagation model	Urban macro, Sub-urban 31.5 + 35log(d) dB, d in m
Carrier frequency	1.9 GHz
Bandwidth	10 MHz
Log-normal shadowing	10 dB
Shadow fading correlation distance	3 $\sim$ 15 km/h: 5 m 15 $\sim$ km/h: 20 m
Max transmit power	53 dBm (43 dBm/MHz)
Transmission bandwidth	10 MHz
Sub-carrier spacing	9.6 kHz
Sampling frequency	9.8304
FFT size	1024
Guard channel	32
OFDM symbol duration	113 us
No. of OFDM symbols	8 symbols per frame
Frame duration	911.45 us
Filter time constant	100 ms
Set update add threshold	–7 dB
Handoff hysteresis	2 dB
Edge loss/gain	3 $\sim$ 15 km/h: 6dB 15 $\sim$ km/h: 3dB

ends when the anchor BS bi-casts user data to these BSs indicated in the request message.

IV. Performance Evaluation

A. Simulation Environment

This section describes our simulation environment, based on IEEE 802.20 MBTDD system model [11][12]. The assumptions used in the simulations are listed in Table I. We consider a hexagonal grid, 19 cell layout network model in which the BS-to-BS distance is 1 km and 2.5 km for urban and suburban scenarios, respectively. The propagation loss is based on the urban and suburban usage models. In order to deal with the slow fading effects, we use log-normal shadowing with standard deviation of 10 dB and correlation distance is set to 5-m for 3 $\sim$ 15 km/h and 30-m for 30 km/h $\sim$, respectively. The maximum total base station transmit power is specified as 53 dBm. The SINR used in the determination of cell switching is obtained by averaging the instantaneous SINR values measured periodically for 100-ms. For a neighboring BS to join the CSS, the set-update-and-add threshold is set to –7 dB. This means that when the received filtered SINR from a neighboring BS is more than –7 dB, the neighboring cell is made to join the CSS. Furthermore, for the execution of handover, the minimum difference of 2 dB between the SINR strengths of the serving BS and the target BS is set as the handover hysteresis value.

For the mobility model, it is assumed that all MSs except one is fixed and the mobility related performance metrics are computed only for this non-stationary MS. A detail description of the mobility models is presented in [13]. The movement of a MS is constrained to two different movement paths. When the MS moves from the serving BS to the target BS along a path joining the cells without any corner effect, it is said to be on Movement Path 1, denoted as MP1. On the other hand, when the MS moves from the serving BS to the target BS with around-the-corner effect, it is said to be on Movement Path 2, denoted as MP2. The around-the-corner-effect is described as the effect that gets generated in urban area usually at the cell boundaries due to sudden change of direction. This leads to an abrupt loss of signal from the serving BS, causing an edge loss and an abrupt signal gain from the target BS, causing an edge gain. In addition, the mobility is assumed to be different in urban and sub-urban scenario. For an urban scenario, we carry out the simulations for both MP1 and MP2, whereas for a sub-urban scenario only MP1 is simulated. The reason for considering only MP1 for a sub-urban scenario is mainly because of a low probability of around-the-corner-effect in suburbs.

In the simulations, for evaluation purposes, we consider some representative velocities from each of these groups; 3 km/h and 10 km/h for the pedestrian group and 15 km/h, 30 km/h and 60km/h for the vehicle group. Similarly, for the sub-urban speed group, 120 km/h and 150 km/h are considered to be representative velocities for range 120 km/h $\sim$ 200 km/h, and 200 km/h for the range 200 km/h $\sim$ 250 km/h.

TABLE II
BICASTING THRESHOLD

	Speed group	bicasting thresholds
Urban scenario	Pedestrian	–5 dB
	Vehicle	–6 dB
	ExpressBus/Train	–7 dB
Sub-urban scenario	120 km/h $\sim$ 200 km/h	–5 dB
	200 km/h $\sim$ 250 km/h	–6 dB
	250km/h $\sim$	–7 dB

Table II lists the bi-casting threshold determined for each mobile speed group in both urban and suburban scenario. We consider signaling overhead in determining the appropriate bi-casting threshold values for each mobile speed group. Then, according to Equation (4) the total time to prepare for bi-casting is assumed to be 1s. That is, before performing handover, the target BS receives user data bi-casting from the anchor BS during 1s.

B. Simulation Results

The performance results for pedestrian scenario are presented in Fig. 3 considering two representative velocities, 3 km/h and 10 km/h. We carried out the simulations for two movements paths described in section 4.1. It can been seen that our propped scheme is efficient in reducing the bi-casting time. For a user velocity of 3 km/h, the bi-casting time is reduced by 49% and 41.5% in MP1 and MP2 scenarios, respectively. Similarly, for 10 km/h velocity rate, 70% and 83.7% reduction in bi-casting time can be noticed in MP1 and MP2 scenarios, respectively. In summary, when the bi-casting threshold of –5 dB is applied, there is a 61.15% decrease in the user data bi-casting time, thus leading to an improvement in the backhaul network consumption.

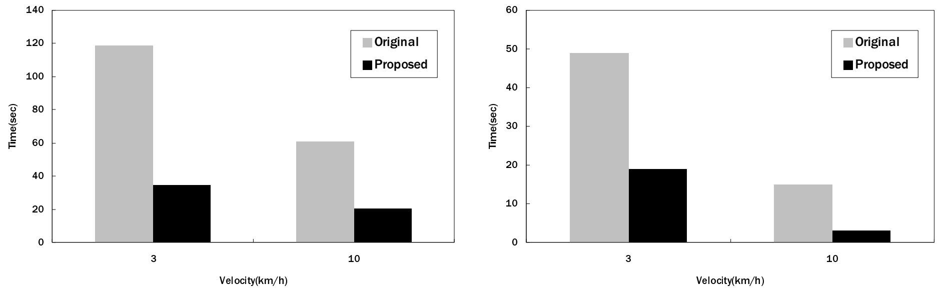

Fig. 3. Simulation results for pedestrian speed group using MP1 and MP2.

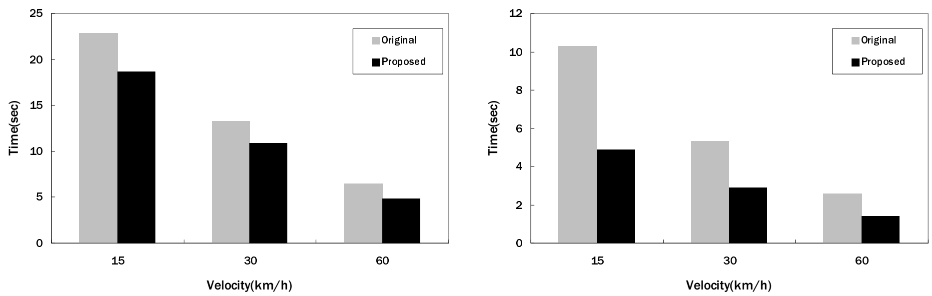

Fig. 4. Simulation results for vehicle speed group using MP1 and MP2.

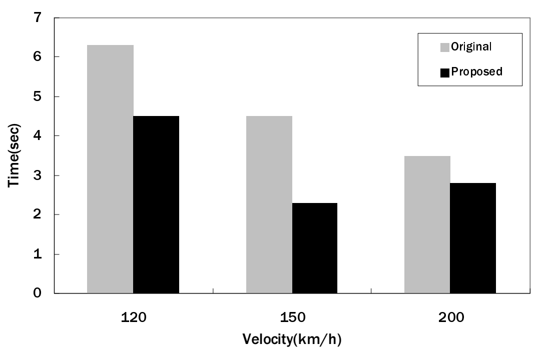

Fig. 5. Simulation results for sub-urban scenario using MP1

Fig. 4 illustrates the simulation results for three representative velocities, 15 km/h, 30 km/h and 60 km/h belonging to vehicle speed group. Again, both the movement scenarios, MP1 and MP2, are considered. When velocity is 15 km/h, bi-casting time reduces to 18.4% and 52.3% for MP1 and MP2, respectively. For 30 km/h velocity, bi-casting time reduces by 18.1% and 45.5%. Furthermore, for a user velocity of 60 km/h, 24.5% reduction is seen in MP1 scenario and 46.1% in MP2. Averaging the obtained results according to the velocity parameter and movement paths, we analyze that using our scheme with a bi-casting threshold of –6 dB, there is a 34.15% reduction in the bi-casting time.

Fig. 5 illustrates the simulation results for a sub-urban scenario. For representative velocities 120 km/h, 150 km/h and 200 km/h, there is 28.6%, 46.5% and 19.7% reduction in the bi-casting time. Therefore, using the above simulation results, we conclude that our velocity-based bi-casting scheme is efficient in reducing the bi-casting time. Hence, an enhancement of backhaul network resources utilization is achieved.

V. Conclusion

In this paper, we propose a velocity-based bi-casting scheme, which reduces the bi-casting time in order to enhance the backhaul network resource utilization in 4G wireless systems. Instead of executing user data bi-casting at CSS update-and-add time, we propose to start bi-casting at the velocity-based bi-casting threshold time. In order to determine the bi-casting threshold for different mobility scenarios, we consider the signaling overhead in finding the appropriate bi-casting threshold and assume that the target BS receives user data from the Anchor BS at least a certain time ahead of handover execution. The performance results show an overall reduction of 61.5% and 34.15% in bi-casting time for the evaluated pedestrian and vehicle scenarios, respectively. Even in the case of sub-urban scenario with high mobility, an average reduction of 31.6% is seen. This accounts for the fact that velocity-based data bi-casting is efficient in enhancing the resource utilization at the backhaul network.

Acknowledgment

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References

[1] IST-2003-507581.: WINNER Final Usage Scenario. D1.3(version1.0):12–14, 2005.

[2] Mobile IT Forum.: 4G Mobile System Requirement Documnent (version 1.1). 4th-Generation Mobile Communication Committee.

[3] Qualcomm Europe.: Cell Switching in LTE Active State(R2-061196). 3GPP-RAN WG2 meeting #53, May 8-12, 2006, China.

[4] Qualcomm Europe.: Intra-System Mobility(R2-060013). 3GPP TSG-RAN WG2 meeting #50, Jan. 9-13, 2006, France.

[5] Qualcomm Europe.: Cell Switching in LTE Active State(R2-061036). 3GPP TSG-RAN WG2 meeting #52, Mar. 27-31, 2006, Greece.

[6] Qualcomm Europe.: LTE Connected Mode Mobility -Technical Document (R3-060209). TSG-RAN WG3 #51, Feb. 2006, Denver,USA.

[7] 3GPP TR 25.913 V7.3.0 (2006-03 Technical Report, 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (E-UTRAN) (Release 7).

[8] G.L Stuber,: Principles of Mobile Communicaiton. Kulwer, 1996: Boston, MA.

[9] G. Azemi, et al.: Mobile Unit Velocity Estimation in Micro-Cellular Systems Using The ZCR of the Instantaneous Frequency of the Received Signal. IEEE Signal Proc. and Its App., Version-1(1) 289-292, July 2003.

[10] M.D Austin and G.L Stuber.: Velocity adaptive handoff algorithms for microcellular systems. IEEE Trans. on Veh. Tech, Version-43(3)549–561, Aug. 1994.

[11] Jim Tomcik.: MBTDD Wideband Mode Performance Report I. IEEE, C802.20-05/66r1.

[12] Jim Tomcik.: MBTDD Wideband Mode Performance Report II. IEEE, C802.20-05/88r1.

[13] 802.20.: Permanent Document,Evaluation Criteria - Ver. 1.0. IEEE P802.20-PD-09.