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Efficiency of the use of LTE system radio resources in highway transport environment

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ABSTRACT

The paper describes the problem of analysis of throughput-coverage characteristics of the LTE system. Simulation results of the efficiency of the use of LTE radio resources are presented. Simulation studies on the basis of original model of the LTE network simulator were carried out. In addition, the evaluation of throughput for a single connection, and available capacity were evaluated in the context of the use of the same available frequency band in all cells of a cellular network. The results were also analysed in view of LTE transport applications. The results shows that from the point of view of transport applications of LTE better results on system performance gives the PFR method.

KEYWORDS: LTE, resource management, ICI, SFR, PFR, transport applications

1. Introduction

The main condition of the effective realization of data transmission services in the Long Term Evolutioin (LTE) system is achieving of large values of SINR (Signal to Interference and Noise Ratio) in a radio interface. It's clear that these values depend on used techniques of signal processing, reception, and also on the MIMO techniques etc. But a very important problem is the effecitve use of system resources and frequency band in all cells in a network. In ideal case, the total frequency band in each cell should be used, what means, that the cellular network is a single-frequency network. But the application of a single-frequency network gives negative consequences as the inter-cell interference (ICI). ICI cause the growth of the total power of disturbances in received signals and, as a consequence, the received SINR value decreases. Then, the throughput in a cell decreases, too.

1.1 High terminals mobility in transport applications of LTE

In transport applications, we have the problem of high mobility of terminals, and high speed of its motion. Then, the process of resource management is strongly important and complicated. In this case, we must use effecive mehods of frequency allocation to system users what depends on their various localization in an area of cell. High speed of motion of terminals causes great changes of ICI received in terminals in connection to another destructive phenomena, such as the Doppler effect, multipath propagation, fast and slow signal fadings etc.

We know that the throughput strongly decreases when the distance from a base station to mobile stations grows. In LTE, where for downlink transmission the OFDMA multiple access method is used, we must make the intelligent subcarriers allocation to all connections which can be carried out in different cells. The method of subcarriers allocation in cells is important because each of these connections can be largely exposed to interferences if it is also used some of subcarriers in adjecent cells.

Moreover, each subcarrier can be disturbed in a small degree if the use of her is limited in adjecent cells. So, the method of subcarriers allocation plays important role in effecitve transmission of signals in transport systems.

1.2 Subcarrier Allocation Methods for LTE

So, in LTE, the use of method of subcarriers allocation in a cell is one of the most significant problems of frequency allocation in cells what can decrease the effect of interference on signal received, especially in mobile terminals. There are two main methods of frequency allocation proposed for LTE. In general, in these methods some parts of frequency bands are allocated for the boundary area of cell (BAC), where the power of the ICI interference is very large in a typical case. Additionally, this part of frequency band is not used, totally or partly, in the central area of cell (CAC) [1], [2], [4]. In this case, some subset of subcarriers (so-called resource blocks) from the total set of subcarriers available in assigned frequency band (the total OFDMA spectrum), is allocated to BAC. If this subset of subcarriers is used at a given moment of time in BAC then it can't be used in the CAC area. There are a lot of papers [1], [2], [3], [4], [5] presenting some ideas for the reduction of ICI for the LTE network. In this paper, both Soft Frequency Reuse (SFR) and Partial Frequency Reuse (PFR) were taken into account. These methods are considered the most promising for the reduction of the effect of ICI on the signal received.

In the case of SFR, an area of cell is divided into two subareas: CAC and BAC. In CAC full frequency band is available for all connections. In BAC only some part of frequency band can be used, i.e. 33 % what is presented in Fig. 1. The band allocated to BAC can also be used in CAC but under the condition that it is not used in BAC at a given moment of time. The problem is that the limitation of frequency band for BAC unfortunately has significant effect on the network capacity limitation in BAC's but it has great effect on ICI reduction and achieving of relative high transmission rates for connections. It is the result of SINR growth in this area.

In the case of the PFR method (see Fig. 2), the full frequency band is divided into two areas in some proportion, i.e. for CAC we can use 70 % of the total band, and for BAC we can use 30 % of the band. But from this 30 % of the band, only the 1/3 is available in a given cell because the two another parts are allocated to adjacent cells only. While the band allocated for CAC is the same in all cells. This method of a band division for BAC areas of adjacent cells guarantees the reduction of the ICI power received in BAC areas what gives great effect on transmission performance and achieving high transmission rates. Due to high ICI reduction we have great values of the SINR received and the result is high transmission rates obtained in BAC areas.

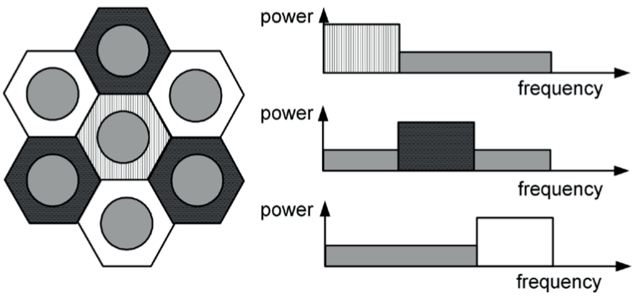

Fig. 1. Frequency band allocation in SFR [own study]

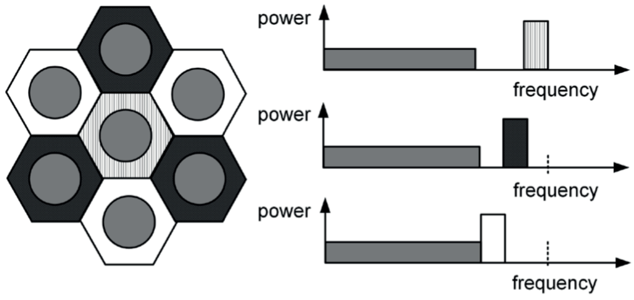

Fig. 2. Frequency band allocation in PFR [own study]

The main problem of the use of the PFR method is large capacity limitation in BAC areas because (i.e. in the case of band allocation presented below) in BAC we can use only the 10 % of full system capacity due to high limitation of available frequency band. Next problem is the capacity limitation in CAC areas when only the 70 % of a total frequency band is allocated. Note, that in the case of SFR we can use total frequency band in all CAC areas. But we have the great advantage of the use of PFR. In this case we have higher stability of achievable transmission rate for single connections which can be realized in BAC areas, especially.

1.3 Requirements for radio resource management in highway environment

From the point of view of transport applications of LTE, in this paper we were taken into account the transmission environment of the highway. We know that in typical urban environments we have the situation where the greatest capacity is necessary due to large number of users which are interested in realization of high rate transmission of data. So, for this environment the method of resource management given greatest capacity is preferred. In this environment typical situation is that simultaneously work from a few to dozens users.

In the highway environment a single base station is used to make coverage e.g. from 6 km to 10 km of the road, the number of active users is much less, and, in typical situation simultaneously work a few users only. So, in this environment a major role plays the stability of achieved transmission rate for connections. But the capacity is not so important.

In literature, we can find a number of publications of comparable results for both the PFR and SFR methods. But in this paper, simulation results are presented from the point of view of the usage of LTE for transport communication along highways. In these conditions large stability of transmission rate is preferred for communication due to high Doppler shift and great speed of terminals.

2. Cellular network simulator

The designed simulation model of the OFDMA-based LTE network is the set of cells in some urban area where we have the central cell (so-called the home cell) and a tier of surrounding cells which generate the ICI interference. Each cell is divided into two subareas: CAC and BAC. The designed R_{CAC} cell radius (a base station range) for CAC area sets the geometrical relation between CAC and BAC in each cell. The R_{CAC} value can be changed during the simulation. In presented research results, the simulated R_{CAC} is: 0.2 R, 0.5 R and 0.8 R (where R is designed cell radius). The use of different values of R_{CAC} gives the illustration of various network configurations [6].

2.1 Network simulation

The simulated network enables observation of the ICI distribution in cells and SINR [6]. On the basis of this information we can estimate throughput-coverage characteristics for connections established in a cell area. If the time of simulation is sufficiently long then we can estimate average value of throughput for connections and evaluate real capacity of network. The full observation is provided for home cell because for this cell we can estimate overall power of interference from adjacent cells. So, presented results correspond to the home cell which is the reference cell.

Table 1. Basic set of simulation parameters [own study]

Parameter	Value
Reuse methods	SFR and PFR
Frequency band	10 MHz
Central frequency	2.6 GHz
Maximum BS power	30 dBm
Transmission type	Single antenna connection
Designed cell radius *R*	400 m
Propagation model	Erceg-Greenstein
Antenna type	Omni-directional
Fast fluctuations	Rayleigh distribution
Slow fluctuations	Log-normal distribution (8 dB signal deviation)
Users distribution	Uniform
Spectrum division for SFR	1/3 (the BAC band / the CAC band)
Spectrum division for PFR	1/10 (the BAC band / the CAC band (30% of full band is reserved for all BAC areas)

If the distance between the base station of the home-cell (BS) and an observed mobile station (MS) grows to the R_{CAC} value, then, in general, the SINR decreases, and achieved throughput for a connection also decreases. But if MS is observed in BAC then the SINR grows again and throughput increases due to the reduction of ICI in BAC. The basic set of simulation parameters is then presented in Table 1. As we can see in next sections, for better interpretation of results, we take into account the distance *d/R* from MS to BS normalized by the *R* maximum cell radius, and the throughput for a single connection C_{MS}/C_{MSmax} normalized by maximum throughput achievable in the network for this connection. As well as, the cell capacity C/C_{max} is normalized by the maximum capacity available in a cell.

3. Simulation results

The network performance is analysed from two different points of view. First, the achievable throughput for a single connection is analyzed as a result of observation of transmission rate stability in different network operation conditions. The second is observation of a network capacity in different areas of cell dependent on ICI received.

The capacity can be understood as the maximum throughput on the area of cell, available for all users in a given frequency band. The channel is composed of many frequency subbands [6], [7], [8]. Each subband depends on the number of allocated subcarriers and resource blocks. So, the capacity depends on network parameters, and on parameters of a single user connection what was taken into account in this paper. The same method of capacity estimation was used for both the simulated SFR and PFR methods including effect of ICI on various areas of a cell (CAC and BAC). It gives possibility to compare the research results which were obtained in comparable network operation conditions and simulation parameters.

3.1 Throughput for single connections

Achieved throughput (i.e. available transmission rate) for a single connection from base station (BS) to a mobile station (MS) is then presented for different localizations of MS's which can be located at various positions in a cell, and at different distance from BS. If the transmitted BS power is sufficient for the best performance of the signal received (SINR) and the system is not capacity limited (so, theoretical capacity is available) then the throughput can be maximal in simulated conditions. These conditions include maximum possible BS power, type of connection, possible modulation-coding scheme etc. If the BS power is not sufficient then SINR is reduced and a throughput decreases. Moreover, this throughput can be reduced if the capacity will be too small in the area observed.

The results of throughput simulation are presented in Fig. 3, Fig. 4 and Fig. 5. There we can see the normalized throughput C_{MS}/C_{MSmax} (normalized by its maximum value achieved when the SINR is maximum) available for a single connection (this throughput not have to be the maximum throughput available in a cell). The throughput is then presented as a function of normalized distance *d/R* from BS to MS where *d* is the distance form BS to MS and *R* is the cell radius.

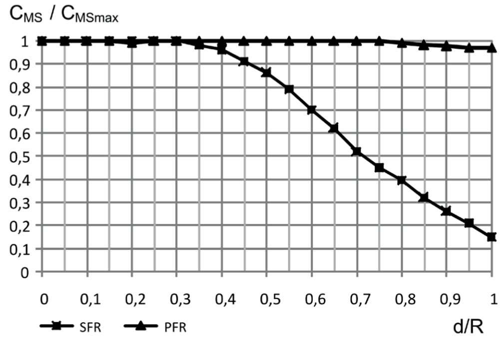

Fig. 3. Normalized throughput C_{MS}/C_{MSmax} for a single connection as the function of normalized distance d/R (R_{CAC} = 0.2 R) [own study]

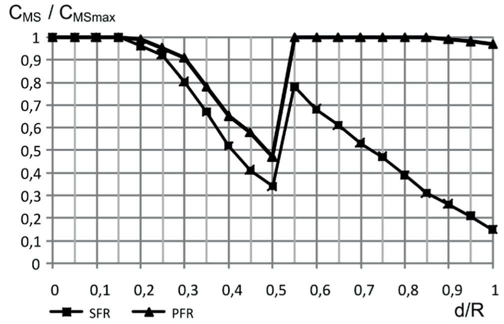

Fig. 4. Normalized throughput C_{MS}/C_{MSmax} for a single connection as the function of normalized distance d/R (R_{CAC} = 0.5 R) [own study]

Presented figures have three variants of cell configuration depending on the cell division onto CAC and BAC areas. Then, we have three R_{CAC} values equal to: 0.2 *R*, 0.5 *R* and 0.8 *R*. We can see that these throughput values will be able to be maintained as shown in the figures, provided that they do not exceed the capacity of the cell, that is, the radio interface load of a cell is not excessive. Achieved throughput is dependent on SINR (in fact – depends on Channel Quality Indicator – CQI) what marks the coding-modulation scheme which achieve predicted transmission rate.

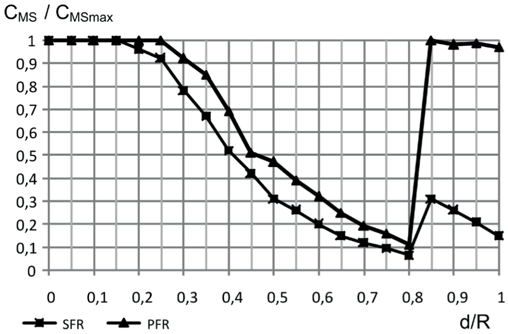

Fig. 5. Normalized throughput C_{MS}/C_{MSmax} for a single connection as the function of normalized distance d/R (R_{CAC} = 0.8 R) [own study]

Note that this research problem of the throughput for a single connection is not researched in most publications but, in fact, it is the most important aspect of network efficiency optimisation from the subjective point of view of real users.

Moreover, the BS power is assigned in the way giving possibility of achieving of maximum SINR in the border of a cell what means that the propagation loss, in general, not limit the BS coverage with assigned design assumptions, provided the deep signal fading.

If the power of signals transmitted by BS is sufficient for achieving of the best quality of signals received in MS which the measure is SINR, and the capacity is sufficient, then the throughput for a single connection is maximum, achievable in simulated operation conditions and assumptions (so, the maximum BS power, connection type, coding-modulation scheme etc.). While the BS power is too small then the SINR achieve less values, and the throughput is reduced.

As we can see, the PFR method gives better results in comparison to SFR. Values of throughput for a single connection are larger in this case, and the result is much better when the CAC area decreases. Note that the reduction of CAC in this method is the same as the reduction of overall capacity in a cell, and when very small R_{CAC} is implemented then the network configuration makes no sense.

The main difference when compared both two methods of frequency reuse is that the PFR guarantees large increasing of transmission rate in BAC areas. But that is achieved as the cost of overall cell capacity. But if for network designers the most important is achieving of large stability of throughput (transmission rate), and typical cell load isn't very large (that means that there are not active the large number of users in typical situation), then the PFR method is preferred.

Note that this situation is typical for cells located along the highways and another ways on suburban and rural areas, so it is typical situation for high-mobility transport applications.

As we can see, the designed values of R_{CAC} plays very important role from the point of view of high efficiency of resource utilization of designed network and their selection is very essential. The throughput for a single connection achieves larger values in a cell when the R_{CAC} is rather small. In this case BAC areas are much greater than CAC. But the capacity for small values of R_{CAC} decreases because the way of radio resource allocation for BAC is much less effective in comparison to CAC what is presented in point 2.2.

3.2 Comparison of capacity-coverage characteristics

The capacity is the maximum throughput for all connections, achievable in a cell, in subareas CAC and BAC which is accessible for all users of a frequency channel [6], [7]. For capacity estimation we take into account the effect of ICI on signal performance, dependent on R_{CAC}, both for SFR and PFR methods.

The research results are presented in Fig. 6, Fig. 7 and Fig. 8 for different values of R_{CAC}. There we can see overall cell capacity C/C_{max} normalized by its maximum value available in the area of cell for maximum SINR obtained (the best CQI).

In these figures we see large variability of a capacity what is the result of various SINR values in different areas of a cell, variability of propagation loss, signal fading and ICI. So, we can see that the use of SFR gives larger capacity in comparison to PFR, both in CAC and BAC areas. While the use of PFR gives large reduction of the capacity for CAC areas in all presented configurations of R_{CAC}. In turn, for small values of R_{CAC} the capacity for PFR is much less in BAC in comparison to the SFR. But, if we take into account large R_{CAC} values then the capacity for BAC is approximately the same for both the PFR and SFR.

Note that the CAC areas, especially for small values of R_{CAC}, in fact, may include its range a relatively small number of users because the CAC area is then relatively small, and the area of BAC is then much greater. In this case, providing very large capacity in CAC may not be at all necessary we can use the PFR for higher stability of obtained transmission rate in overall area of cell.

It is also seen that the SFR method gives good results of the capacity, provided proper selection of CAC and BAC areas, which is the R_{CAC} radius.

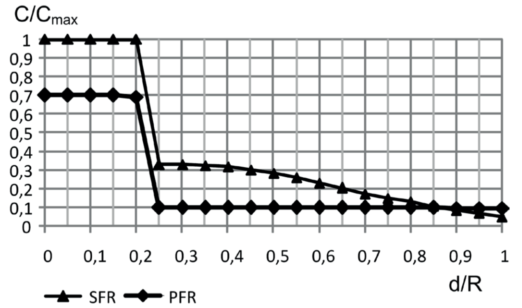

Fig. 6. **Normalized capacity C/C_{max} as the function of normalized distance d/R (R_{CAC} = 0.2 R) [own study]**

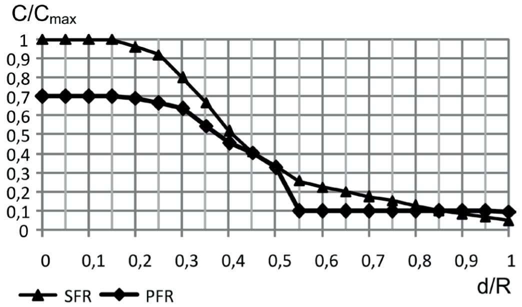

Fig. 7. **Normalized capacity C/C_{max} as the function of normalized distance d/R (R_{CAC} = 0.5 R) [own study]**

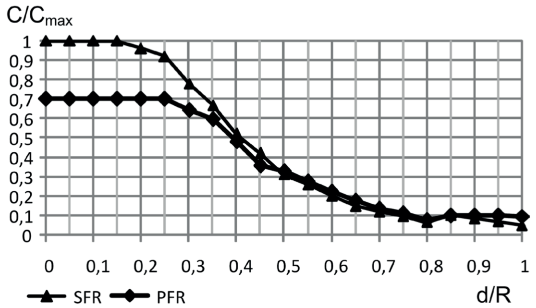

Fig. 8. **Normalized capacity C/C_{max} as the function of normalized distance d/R (R_{CAC} = 0.8 R) [own study]**

3. Conclusion

In the paper the comparison of PFR and SFR methods efficiency in the LTE network is presented from the point of view of their usage in highway environment. We can see that PFR guarantees higher stability of achieved throughput for a single user in comparison to SFR. But simultaneously it is done as a cost of achieved maximum throughput for all users, i.e. the capacity for different areas of a cell. We can see that the capacity in CAC and BAC areas is in general greater for the SFR method.

Achieved results remain in close connection with the selection of the R_{CAC} radius which defines the designed size of both the CAC and BAC areas. When selecting the radius we must take into account the effect of ICI on factual throughput achieved for a single connection because the throughput-coverage characteristics for a single connection are significantly different from capacity-coverage characteristics in a cell.

Taking into account this proposal in the network design process is a condition of the proper use of both PFR and SFR. Presented comparison allows rational choice of frequency reuse method depending on design assumptions.

For the case of the use of both the PFR and SFR for the applications of LTE dedicated to transport systems, especially for communications along the highways and other national roads, better results give us the PFR method because it gives higher stability of achieved transmission rate. This is very important in high-mobility network where vehicles move at high speeds.

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