AN ANALYSIS OF 3G-4G TRAFFIC GUIDANCE METHODS

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Abstract: *As the LTE radio access technology is deployed in more and more world areas, a new challenge - apart from the well-known signaling and scalability issues - arises. The need to direct all the radio mobile network's subscribers' traffic optimally and the question of whether to choose the legacy networks or the new and improved one become problematic. This paper discusses a number of traffic directing methods, compares them with a series of criteria and offers recommendations regarding network choices, based on points of view like LTE penetration, traffic volumes, and subscribers' LTE capabilities.*

Keywords: *3G,4G, traffic methods, simulation, carrier, throughput.*

1. INTRODUCTION

Next generation wireless networks are designed in order to be operational in areas where there already is signal coverage provided by other networks of different technologies, e.g. 2.5G, 3G, LTE. These new networks have the ability to integrate radio access technologies such as Long Term Evolution and LTE-Advanced over existing networks: GSM (Global System for Mobile Communications), UMTS / HSPA (3GPP Universal Mobile Telecommunications System / High Speed Packet Access) and Wi-Fi (Wireless Fidelity) [1, 2].

All types of networks mentioned above work with different sets of frequencies and each of them use particular cell sizes. These dimensions can vary from macro-cells that can have an approximately 15km diameter, to pico or femto-cells that are typically used in order to provide additional coverage in small areas or so-called "islands".

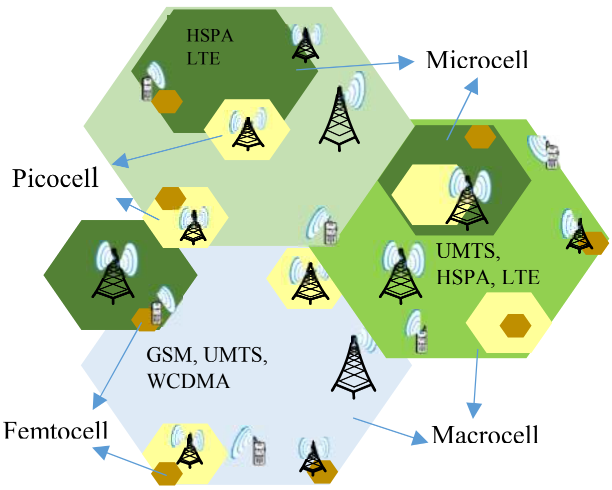

FIG.1. General mobile network infrastructure

Interconnecting these networks is not without a number of difficulties. The main problems include: traffic congestion, interference management in the numerous cases of overlapping channels, continuous adjustment of the small cell coverage, handover procedures between all the networks involved and directing traffic to the network able to offer best performance from the points of view of both the subscriber and the network. The scope of this paper is choosing the optimal traffic directioning method, when faced with different congestion scenarios, which attempt to resemble real-life situations as much as possible.

2. TRAFFIC COORDINATION ALGORITHMS

Traffic coordination assumes that it would be directed towards a carrier belonging to a radio access technology, which would be available at that moment, and which would transport the respective service to a subscriber or a number of subscribers. This aspect may cause significant load on the signaling network. Consequently, several criteria in above question must be taken into account, such as resource load balancing, minimizing end user terminals power consumption as well as signaling headers, being among the most important [3-7]. These aspects are all chosen keeping in mind the growth of end user satisfaction. Also, these objectives are all in direct correlation with the traffic directing policies of each mobile telecom operator.

There are a number of articles concerned with load balancing and handover parameters, as discussed in [8] and [9]. These all are presented regarding the LTE radio technology; [10] present a number of traffic directing types and their respective planning.

This article discusses several methods for coordinating traffic between HSPA and LTE on the downlink direction of the macro-cells, aiming to maximize the transfer rate or the flow of traffic, measured at the subscriber's terminal. Based on a theoretical model for coordinating traffic, the best traffic load balancing between the two carriers is estimated. It also assesses the impact on end user terminal capabilities.

The study of traffic coordination in 3G and 4G networks can be done using a number of methods that can be classified as static or dynamic, taking into account the carrier capabilities and the way their load is managed. The methods of coordinating users on different carriers can be made using different possibilities ranging from the use of random techniques, to considering the SINR parameter (Signal to Interference plus Noise Ratio) and the instantaneous traffic load as a starting point for the calculation.

Taking into account the access to services provided by mobile networks, this study starts from the premise that directing subscribers is possible only when connected and afterwards every subscriber will remain active and does not intend to receive services in another carrier than the one which is assigned to it, from the connection moment until the call is terminated.

The carrier capacity is defined as the average cell throughput (measured in Mbps), and the load is assessed by the number of users on a particular carrier.

2.1. The random method (A)

The random method randomly directs subscribers towards a carrier. For instance, considering the case of having 2 carriers, approximately about half of the subscribers are directed towards each carrier, but, at a given time, their distribution on those 2 carriers may be not even close to equal. The main benefit of this method is the absence of any prior load or traffic information necessity. The random method is a static method.

2.2. The "Best Carrier" method (CMBP)

This method relies on the fact that carrier's capabilities are known. A number of subscribers is defined, chosen by the operator, which will be coordinated to each carrier. It is recommended that the number of subscribers that will be directed should be chosen in order to maximize traffic flow. The target is to achieve a more balanced load between the carriers that are supposed to have equal capacities.

CMBP method may be used in combination with the random method. An operator wishing to use the best carrier method can only define a relationship of load-bearing between carriers and users can be directed randomly to any carrier according to the report previously defined.

The INR or the load of any carrier at any given time will not be taken into account for this type of hybrid traffic directing method.

The best carrier method is also a static method.

2.3. The Subscriber Load method

This method, unlike the two above, directs traffic dynamically, keeping account of the loading of each carrier. The goal is that subscribers should be directed to the carrier with the lowest normalized load.

Normalized load [1] is defined as the ratio between the number of subscribers of each carrier and the carrier capacity

$$\arg\min_{N_p \in P}\left(\frac{nUN_p}{CN_p}\right)$$

where the arg min (arguments of the minima) are computed considering

N_p = carrier number

nUN_p = the number of users of the N_p carrier

$C N_p$ = carrier capacity

P = the range of available carriers (be them from the same layer or from overlaid layers)

2.4. User Throughput method (DTU)

The starting point of this method is the estimation of each carrier's traffic mean, for a subscriber that attempts to connect to the mobile network. This estimation takes into account three parameters:

- the SINR of that subscriber, which in turn is determined by a stochastic model;
- the number of active users of each carrier;
- a throughput curve for each carrier that tracks the flow of traffic of SINR to the user. The latter can derive from Shannon's formula or can be determined from each operator's measurements.

The user *u* will be directed towards the N carrier that is offering the maximum possible throughput (T_{max}). As such, the mean user throughput can be estimated as follows [9]:

$$T_{med} = \frac{SINR_{T\max}(SINR)}{nUN_p + 1}$$

$$\arg\min_{N_p \in P}(T_{med})$$

where SINR = SINR of user *u* which is placed on carrier N_p

$SINR_{Tmax}$ = the function which is mapping the user SINR to its throughput (this is just for a single call)

T_{med} = mean throughput estimation carrier N_p

3. MODELLING TRAFFIC DIRECTIONING

Directing traffic can be done depending on the carrier used and this is based on a Markov process that directs traffic between two radio access technologies. Supposedly there are two carriers, P1 and P2, between which traffic directing is analyzed.

There are two states regarding the two carriers, which are named Px,y, where

x = number of users belonging to carrier 1 (x=0 ... N_1)

y = number of users belonging to carrier 2 (y=0 ... N_2)

λ_1 = probability to receive new calls on carrier 1

λ_2 = probability to receive new calls on carrier 2

It is assumed that the probability to receive new calls is independent of the number of subscribers on a particular carrier.

μ_1 = probability of a call to end on carrier 1

μ_2 = probability of a call to end on carrier 2

It is assumed that all subscribers are generating equal amounts of traffic. It is also assumed that the whole capacity of a carrier is equally split among all subscribers which are using it.

N_1 = maximum user number belonging to carrier 1

N_2 = maximum user number belonging to carrier 2

The aspects described above lead to a Poisson process that can map equal probabilities of calls sent and received.

The probability of a call to end when it is situated on a layer that can carry *n* subscribers can be represented using the formula: $\mu = \frac{C}{A}$

where C = cell capacity where the user is connected [bps]

A = bit size of the call

It is assumed that A is not system-dependent. C is different because it depends on the carrier.

Using the information presented in [11], the state probability can be expressed as follows

$$P_{x,y} = P_x \cdot P_y,$$

where $P_x = \frac{\left(\frac{\mu_1-\lambda_1}{\mu_1}\right)\cdot\left(\frac{\lambda_1}{\mu_1}\right)^x}{1-\left(\frac{\lambda_1}{\mu_1}\right)^{N_{G3}+1}}$ and $P_y = \frac{\left(\frac{\mu_2-\lambda_2}{\mu_2}\right)\cdot\left(\frac{\lambda_2}{\mu_2}\right)^x}{1-\left(\frac{\lambda_2}{\mu_2}\right)^{N_{LTE}+1}}$

Each user's mean throughput can be calculated as being the mean throughput of a state depending on this state's probability. As such, the mean throughput for an user belonging to carrier 1, can be defined as follows

$$D_{P_1} = \sum_{x=1}^{N_1} \sum_{y=1}^{N_2} P_{x,y} \cdot \frac{C_1}{x}$$

where C_1 = carrier 1's capacity.

Being given any cell, different subscribers have different bit rates depending on the place they occupy in the cell, from a geographical point of view.

For example, a subscriber situated at the edge of the cell will have a much lower speed compared to a subscriber located near the antenna that is placed in the center of the cell.

The likelihood that a user will benefit from the traffic flow of*t*, can be expressed as a function of traffic flow *t*, assuming no other user on the same carrier is using all the resources of the cell.

It is assumed that there is no other subscriber on the carrier so that the subscriber in question benefits from all of the resources of the cell.

Depending on the location of the subscriber in the cell, the bit rate that it benefits from may change. Thus, one can estimate the probability of bit rate *r* has on the carrier 1 as:

$$P\left(D_{P_1} = t\right) = \sum_{x=1}^{N_1} \sum_{y=1}^{N_2} P_{x,y} \cdot f(xt)$$

This analytic model can also be used on the algorithms described above. For example, considering the random algorithm, λ_1 will be equal to λ_2. In the case of the CMBP algorithm, several values of λ are required.

4. PROBABILITIES SIMULATION

In the simulations presented below, subscribers per cell records are generated according to a Poisson distribution. SINR values of subscribers are drawn from a SINR distribution that differs depending on the simulation scenario chosen. The simulation was made using OPNET with vendor-specific plug-ins.

The chosen scenario is 3GPP macro 3, which is used by an operator from Romania where the average distance between sites is 1600m. The SINR of each subscriber is considered to be constant during calls because it is assumed that subscribers do not move significantly. Consequently, fading phenomenon is also negligible.

Table 1 The simulation parameters.

Traffic coordination method	A, CMBP, IU, DTU
Load	2; 4; 6; 8 Mbps
User generation	Poisson arrivals
Planning algorithm	Round robin
HSPDA user class	$\leq 15\ codes\ ;\ \leq 64QAM$
LTE coverage	100%
Antenna configuration	1x2 antenna
Channel Bandwitdh	3G and 4G: 5MHz
Traffic model	Finite buffer 600kB

Two carriers are considered, the LTE "high" frequency one of 2.1GHz and the 3G "lower" frequency of 800 MHz. The cumulative distribution function (which traces the bit rate difference between subscribers) differs by a level less than 1 dB between the two radio access technologies (3G and 4G). It is also assumed that cell resources are shared equally among all active subscribers.

5. RESULTS

In this section the numerical results concerning the static methods of directing traffic (random method and the method of "the best carrier") compared to the results of the analytical method, will be discussed.

Figure 2 shows 10% of traffic flow in Mbps when using static methods, depending on the possible load of the cell. 3G and 4G curves indicate 10% of the traffic of 3G and 4G technologies when using the random method. When using the CMBP algorithm there can be seen an improvement over the random method. The reason the random method can not improve its results is because of the congestion that occurs on the 3G carrier as the traffic is approaching the 50% threshold. Also, the figure indicates that there is a significant approach between the simulation (sml) results and those of the analytical (anl) method.

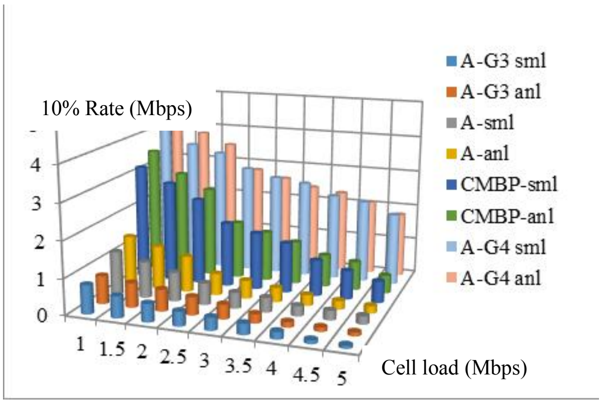

FIG.2. 10% of traffic flow depending on the cell load for the random and "best carrier" methods compared to the analytical method and results of the simulation

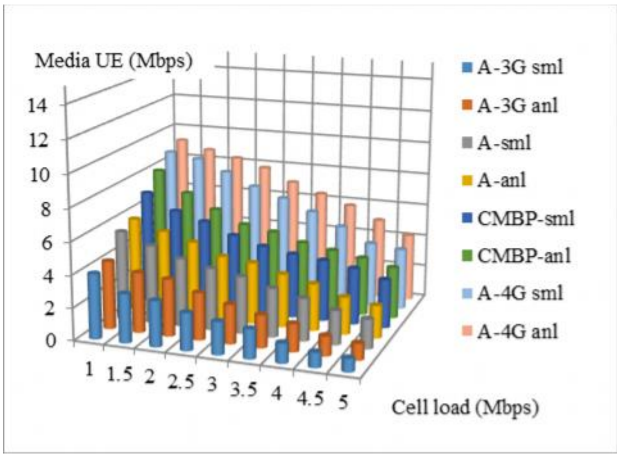

FIG.3. Comparison of average subscriber throughput in terms of analytical results and in those of the simulation results.

Fig.3 depicts average traffic flow based on cell load considering the same conditions as those of fig.2. Here it can be seen that the random method has similar performances in particular 3G and 4G cases compared to the case when this method is applied to both radio access technologies.

The method "best carrier" is proving to be more effective than the random method. Generally speaking, the analytical results are aligning with those obtained from simulations.

A cell load limit of 5Mbps has been chosen because the simulation results lose precision when the system load exceeds 6Mbps. Thus, the analytical model is valid only for stable systems. If a higher load of 6Mbps is desired, the analytical model is not recommended.

It can be concluded that the field results resemble a lot to the expected results from theoretical analysis. Also the best carrier method had the best performance and thus, this method will be used as the benchmark in the next section.

An analysis between the load-based method and the traffic flow method, based on the subscriber's throughput, both compared to the CMBP method.

Fig.4 depicts the average throughput depending on the available cell load. Here, the method "best carrier" has the worst performance. Note that the network becomes congested at a load higher than 6 Mbps.

Thus, when using the CMBP method, subscribers situated at the edge of the cell do not receive a high quality signal. Instead, other methods manage to provide an acceptable data rate which can increase when the number of connection requests grows.

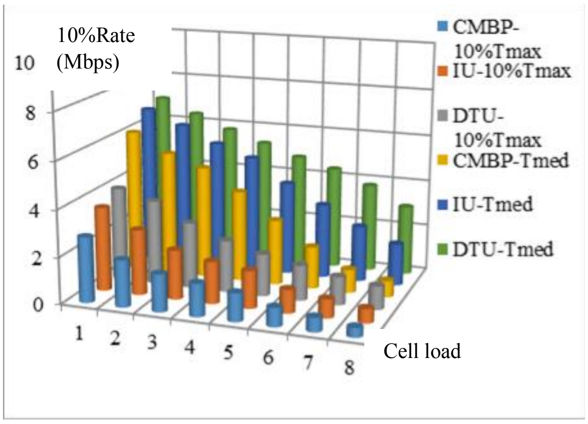

FIG.4. 10% user data rate, depending on cell load

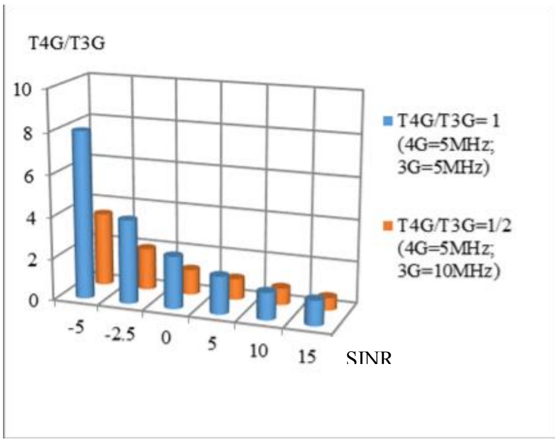

FIG.5. 4G throughput gain compared to 3G

Looking at the throughput, the load-based method and the throughput-based method offer better quality, when compared to the best carrier method. For loads up to 5 Mbps, the two methods in question have close performances, so it can be concluded that there is no gain when the subscriber's SINR is also taken into account. At loads of over 5 Mbps, the subscriber's throughput-based method has proven to be the best algorithm.

For 6 Mbps uploads, i.e. the load used in the previous case, the CMBP method used to offer a 1.3 Mbps speeds. Using the same load, the load-based method and the throughput-based method offer speeds of 2.7Mbps and 3.4Mbps, respectively. This can translate into gains of 112% and 162%.

These gains can not be regarded as entirely real. They appear to be so high because the CMBP method does not use information "photographed" at a particular moment in time, but it is based only on the carrier's capabilities. In contrast, the other two methods are directing subscribers while taking into account information such as instantaneous load on the carrier at a particular moment in time and thus allow a dynamic alignment to the cells' and network's requirements.

The large gain obtained by the throughput-based method comes from instantaneous SINR subscriber information processing. The SINR of the subscriber is used to estimate the throughput per subscriber for each carrier, given an instantaneous load.

Figure 5 shows the 3G and 4G throughput ratio, depending on SINR. Given a small SINR, the 4G throughput is about 7.5 times greater than the 3G one. On the other hand, considering high values of SINR, the above mentioned ratio drops to around 1.5 values. This graph was presented in terms of a of 5 MHz bandwidth.

Hence it can be concluded that the subscriber's throughput method leads the lower SINR subscribers towards the 4G technology and those with higher SINR to the 3G carrier. The imperative condition is to maximize traffic flow, according to the formulae regarding the subscriber's throughput.

It should be kept in mind that such a gain resulting from the use of the throughput-based method depends on the ratio of subscriber traffic flow between 4G and 3G.

This ratio is calculated depending on a number of factors specific to each operator, such as each system's spectral efficiency, using or not using MIMO (Multiple Input Multiple Output) and so on. The closer to 1the ratio 4G / 3G is, the lower possible gain becomes, when using the throughput-based method compared to the one based on subscriber's load.

6. THE IMPACT OF SWITCHING TO 4G

This paragraph will consider two cases in which 3G and 4G, both with bandwidths of 5 MHz, have loads of 2 Mbps and 5 Mbps. For the third case the bandwidth of 10 MHz for 3G (Dual Carrier) and 5 MHz for 4G is considered, and the load is 5 Mbps.

Fig.6 shows the average throughput gain when using the throughput method versus CMBP in all the three cases above.

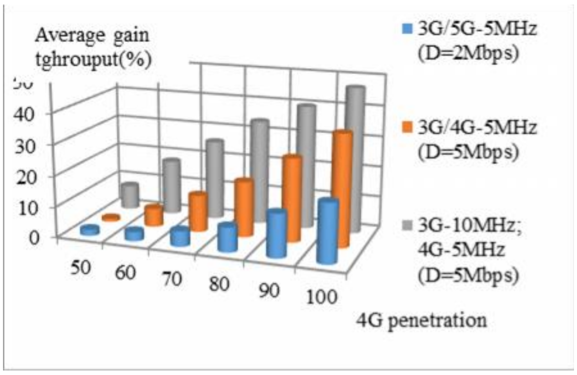

FIG.6. Average gain from the throughput point of view based on 4G penetration, using the throughput method versus best carrier method

The graph is described depending on the subscribers' capability of using LTE. It starts at 50% and is reached if all subscribers are able to use the LTE technology.

If the optimal case, e.g. 100% LTE capability, the gain from using the traffic-based algorithm is greater for a higher load, but this aspect can be extracted from figure 5 also. The explanation resides in the fact that on smaller loads, the probability of having few subscribers on a carrier is high, thus in this case there was no significant difference between methods.

When using 3G Dual-Carrier, the gain is bigger than LTE's, disregarding the LTE penetration. In this case, we basically have two carriers instead of one, so the throughput doubles, so most subscribers will be directed here, as shown in Figure 6. Consequently, the gain of the throughput method is higher because this algorithm can highlight this issue, unlike the method CMBP, which chooses its subscribers randomly.

For a network with 5 MHz bandwidth, all subscribers sent towards LTE will notice a gain, even if the biggest appears to subscribers on the cell edge that are also directed to LTE, but they have the slightest influence on the cell throughput therefore they would have received a smaller gain, have they used the throughput method.

It may be admitted that in all 3 cases, the gain using the throughput method decreases in direct proportion with the LTE capabilities of the subscribers. This is because when not all subscribers can use the LTE technology, they will be directed towards the 3G carrier, even if it is not the optimal solution. Situations can occur where everything that the throughput method can do is to direct all subscribers with LTE capabilities to the LTE carrier.

Quality-wise, this method is not different at all from the CMBP method. In these circumstances there is no gain from employing the traffic flow versus the “best carrier” one.

From the level of penetration of LTE technology point of view, at a level of maximum 45%, it can be concluded that the best method carrier offers the same performance as the more advanced methods.

When LTE penetration is increased to minimum 70%, then it is recommended to use a more advanced method. The inflection point, i.e. when deciding when to change the method, depends on the field conditions. For example, if the LTE carrier capacity increases and LTE penetration is high, then a simpler method is enough. On the other hand, if the capacity of other carriers rises, and LTE penetration is reduced, then it is recommended the use of a more advanced traffic direction method.

The amount of traffic should also be taken into consideration. In this case it was considered that each subscriber generates the same traffic volume and is independent of the terminal type. But it is expected that LTE subscribers will generate more traffic than the 3G ones, and so there arises another reason for using advanced methods when having reduced LTE penetration.

7. CONCLUSIONS

This paper presented a number of static and dynamic traffic directing methods. Static methods, the random and the "best carrier" were analyzed and then compared with the dynamic methods that were simulated using close to reality cases, and the results showed significant similarities in certain conditions.

Considering complete LTE penetration, it has been demonstrated that the dynamic throughput-based method, shows better results than all of the other methods discussed above.

It has been demonstrated that dynamic methods, based on both the subscriber load and the subscriber throughput, show gain only when the LTE penetration level exceeds the 70% mark. Below this level, we see that the "best carrier" method provides as good results as the ones from the dynamic methods.

The inflection point, i.e. when it is recommended to make the transition from one method to another, depends on the amount of generated traffic and subscribers’ capabilities to connect to the LTE technology.

In conclusion it can be said that choosing the best traffic directing method depends mostly on the level of LTE penetration. When this is high, the use of dynamic methods is recommended because they can detect cell load at a given time, and when penetration is not significant, it is recommended to direct all subscribers with LTE capabilities to the carrier with the same name.

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