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A System to improve the management of 5G and IoT Networks by determining the Mobile Position

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***Abstract* - The interference in adjacent cells and the control of the boundaries have being vastly investigated since the conception of the first cell phone networks. A very large number of small cells are required for new 5G mobile networks, and therefore it is even more important to determine the correct mobile station positioning as well as the control boundaries. In order to minimize these problems, this paper proposes a simple and efficient system that improves the control of the Mobile Management Entity (MME) defined in the Release 8 of 3GPP. The system uses a tracking arrangement capable of determining the direction of the mobile station in the cell area. This information can be used to predict handover between adjacent nodes (changing of cell) minimizing a great problem, the high traffic in the backhaul network. In order to reach these goals, two or more receiver antennas are used as a Radio Direction Finder (RDF) and phase controlled directional antennas or massive multiple-input and multiple-output antennas pointing to different irradiation channels towards different directions. The theoretical section developed in this study was successfully confirmed by the experimental setup with results very closed to the developed formulation.**

***Index Terms*—**5G mobile communication, Controlled Beam antennas, Internet of Things, Radio direction finder.

I. INTRODUCTION

In the last few decades communication systems have evolved from fixed-lines to incredible mobile data communication. Nowadays, we have witnessed an expanding of data traffic due to both the number of devices connected, and especially the multimedia demand for high data rates [1]-[2]. It is expected that the number of mobile connections will grow significantly, due to the fast growth of wireless consumers and also the new concept based on the Internet of Things (IoT) [3]-[6]. This exponential increase in mobile system traffic will be supported by the new Fifth Generation (5G) of cellular technology. The 5G goes beyond human to human communication, introducing new concepts, such as, machine-to-machine communication (M2M) and the IoT [7]. At this point, a multiservice system must be developed to provide multiple types of services in the same baseband system [8]. The

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conceptual carrying out of these high-level technologies brings up new challenges for physical infrastructure designers. The frequency reuse and sectorized base station technologies were developed and applied to minimize the interference in adjacent cells, but in the third generation (3G) cellular networks the densification of macrocell base stations (BS) increased and is about 4-5 BSs/km^2. In the fourth generation (4G) cellular networks such as Long Term Evolution-Advanced (LTE-A) is approximated 8-10 BSs/km^2. The density of 5G BSs is anticipated to come up to 40-50 BSs/km^2, therefore the 5G cellular network is an ultra-dense cellular network and new technologies must be deployed. High gain multibeam antennas (MBAs) capable of covering a predefined angular range are potential solutions to overcoming the shortcomings of single directive beam antennas [9]-[10].

The ultra-dense small-cell and the change of cell area problems are being subject of many studies. In the paper [11], H. Raza makes a survey of the backhaul technologies used in the LTE Radio Access Network, pointing out the LTE requirements and their impact on the backhaul network. L. Xu et al. in [12] suggest using cognitive radio technologies to access vacant spectrum holes in various wireless technologies and show that this technology improves the spectrum efficiency and that is an important scenario for 5G networks. In [13] the authors propose a distributed routing scheme to reduce the backhaul traffic in ultra-dense small-cell networks. They show that the Multipath Multihop (MPMH) backhaul is the most cost-effective and scalable solution in Small-cell Ultra-dense Networks. In the same way, A. Jain et al. in [14] present a new network entity called MME-SDN that optimizes the handover process in the next 5G networks, providing a 48.83% reduction in latency. The “Multi-Homing in Unlicensed LTE Networks” in [15] shows the Radio Access Technologies selection and resource allocation when unlicensed networks like WiFi are used. The numerical results demonstrated that the proposed multi-homing scheme improves the network performance. A. Habbal et al. in [16] show that an efficient RAT (Radio Access Technology) selection mechanism in ultra-dense networks is required. They proposed a new mechanism for RAT selection to be applied in Ultra-dense Networks and proved that it reduces the number of handovers and it is less susceptible to abnormalities.

Based on this new scenario and studying current networks, this paper proposes a technique to increase the management capacity, reduce the backhaul traffic and reduce interference between cells.

The remainder of this paper is organized as follows: Section II describes the current system used to manage mobile stations defined by 3GPP. Section III presents the antennas used nowadays by the base stations. Section IV shows the proposed system methodology, and discusses the changes and the benefits of our technique in the current 3GPP cellular networks. Section V shows the theoretical development and practical tests. Finally, the Conclusions are given in Section VI.

II. TRACKING AREA UPDATE

The tracking area concept was introduced in Release 8 of the 3rd Generation Partnership Project (3GPP). Basically, a Mobile Management Entity (MME) keeps records of the location of the mobile stations inside the tracking area. When a connection request comes for an equipment in idle mode, the equipment in question is paged within its current tracking area [17]. *Fig.* 1 illustrates the cell division in a network, the letters A to G represent the coverage areas of each radio-base station.

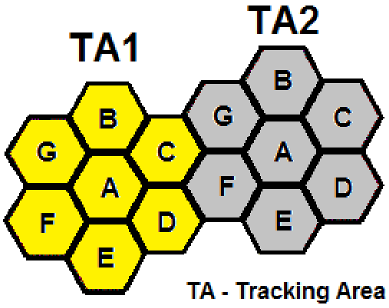

Fig.1. Design of tracking areas in a network.

When a mobile station moves from a tracking area to another tracking area the information about the current position must be updated supporting the MME to control the network. In order to have a current list of mobile stations in the network, the MME sends a paging request to all coverage cell areas, resulting in a poor performance of both the transmission link and the backhaul [18]. Thus, an improvement in the localization system will increase the efficiency of the MME and decrease the traffic in the backhaul, as will be demonstrated in section IV.

III. PASSIVE MULTI-BEAM ANTENNAS AND MIMO ANTENNAS

For the next fifth-generation (5G) of wireless communication, the limited spectrum resources available in the sub-6GHz spectrum no longer satisfy the system requirements. Recently, the International Telecommunication Union has considered the spectrum for 5G communication around the 24.25 to 27.5 GHz, 37.0 to 40.5 GHz, and 66 to76 GHz bands [19]. Although these new bands support both high data rates and a greater number of mobile stations, the high frequency electromagnetic waves suffer severe free space losses and blockage. The use of high-gain antennas with directional beam greatly enhances the signal-to-noise ratio (SNR). However, in general, directional high gain antennas are not a multiuser mobile alternative, due to their limited spatial beam. Alternatively, the multibeam antennas and the multiple-input multiple-output (MIMO) antennas provide a solution to overcome the limitations imposed by the single directive beam antennas [10].

Multibeam systems allow significant frequency reuse and yield much higher system capacities. In principle, passive multibeam antennas contain a finite number of well-isolated input ports, and each port is backed by a transceiver beam pointing in a predefined direction.

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Fig. 2 illustrates the irradiation diagram of a Multibeam antenna. If the direction of the mobile station is defined, it is possible to take advantage of the directionality of these antennas as will be demonstrated in section IV.

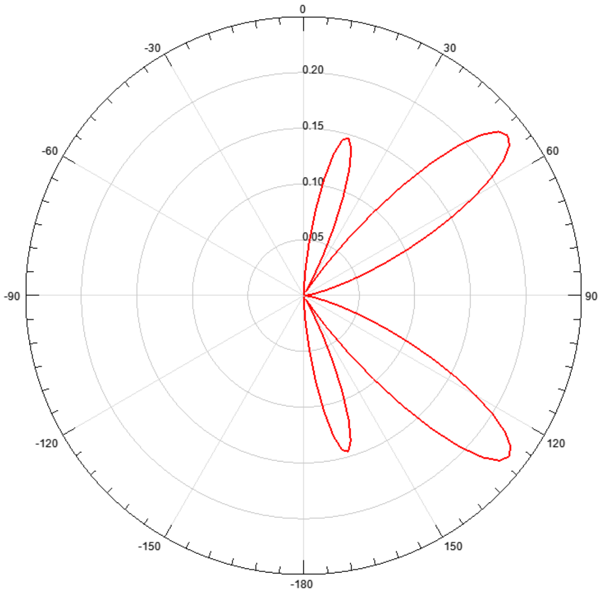

Fig. 2. Multibeam irradiation diagram.

IV. THE METHODOLOGY AND THE PROPOSED SYSTEM

One of the most important features that differs 5G technologic from previous technologies is the use of small cells called Home eNodeB or Fentocells. These small cells require the same treatment given to the large cover cells relative to the control of mobile stations and coverage area. In the current system the cell change is performed by the eNodeB station or the MME (Mobile Management Entity) connected in the backhaul. Therefore, increasing the number of small cells, increases both the interference between cells and the backhaul traffic. In order to evaluate the impact in this new scenario an analysis of the current system was informed. For the new generation it is desirable to find methods that optimize the management, reducing the backhaul traffic and reducing interference between cells. Based on that, this study proposes using two antennas working as a tracking system as described in section V. In order to confirm the viability of this system, experimental tests were performed and the practical measurements were compared with the results obtained from the equations determined by the theoretical study.

In this proposed system the signal sent by the mobile station is received by the tracking system and sent to the Mobile Management Entity (MME) that receives the traffic data and the position of the mobile station. Based on the position of the mobile station, the MME adjusts the phase of the transmitter and beam in the direction of the mobile station. It is important to note that each channel has its own control. The transmission to each station is done by adjusting the individual step phase of the channel based on the received position. *Fig.3* shows the proposed system for only one channel.

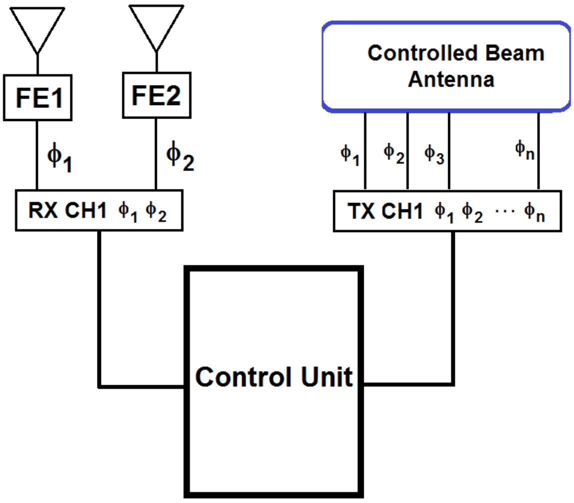

Fig. 3. Individual channel control.

The whole system has the track antenna system, the receiver, the control unit capable of store a list of mobile stations and their positions, the transmitter and the reconfigurable beam antenna, as shown in *Fig.4*.

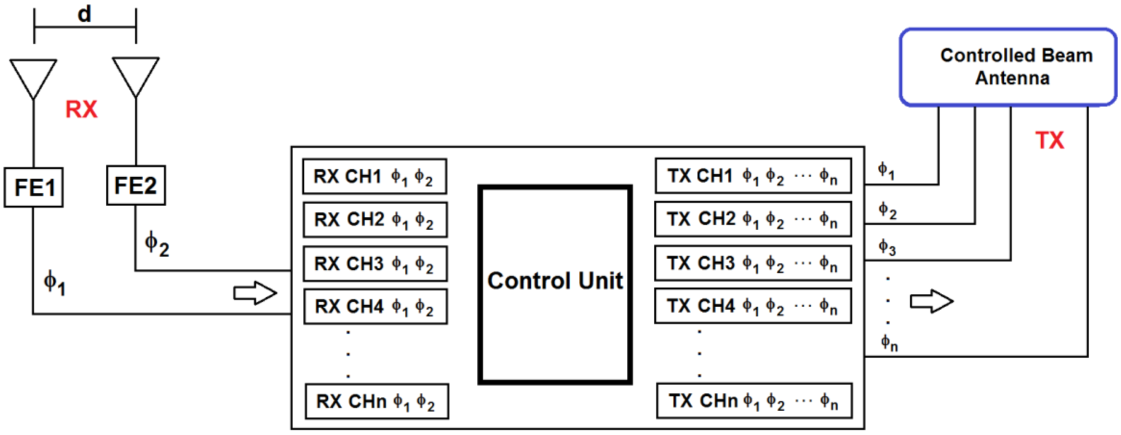

Fig. 4. Complete Track and Beam system.

Once the transmitter is adjusted to irradiate in the direction of the mobile station with controlled power, it is possible to increase the distance range and reduce interference in the whole system. Another interesting feature of this system is that, by knowing the position of the mobile station, the MME can reduce the requested traffic only by determining where the mobile station is, and predicting the change of the tracking area. For instance, in *Fig*. 1, if the mobile station is in the 'A' cell near the border of cells 'C' and 'D', the MME must send the request signal only to cells 'C' and 'D', and not to all (B,C,D,E,F,G) cells as it is currently done.

received 28 Jan 2019; for review 05 Feb 2019; accepted 03 May 2019

V. THE RADIO DIRECTION FINDER AND TRACKING SYSTEM

Radio Direction Finder (RDF) is an old concept used in aircraft navigation. Early systems used a loop antenna with a deep null signal point used to tune a transmitter station in low frequency band, called Non Directional Beacon (NDB). In the modern systems, two antennas are required, a loop antenna and the sense antenna. The loop antenna has its maximum voltage when the antenna coil is perpendicular (90º and 270º) to the transmitter and two nulls at 0º and 180º. The sense antenna is an omni-directional antenna mounted with the loop antenna in the same housing. This system is called Automatic Direction Finder (ADF) [20].

In a typical ADF receiver, the signals received by the loop and the sense antennas are combined to create the equivalent of a cardioid pattern. At high frequencies there is an alternative way to determine the direction of the signal, since the wavelength is short, it is possible to measure the difference between phases of two signals that arrive at different antennas [21]. The radio direction finder proposed in this work is composed of two antennas as illustrated in the *Fig.5*.

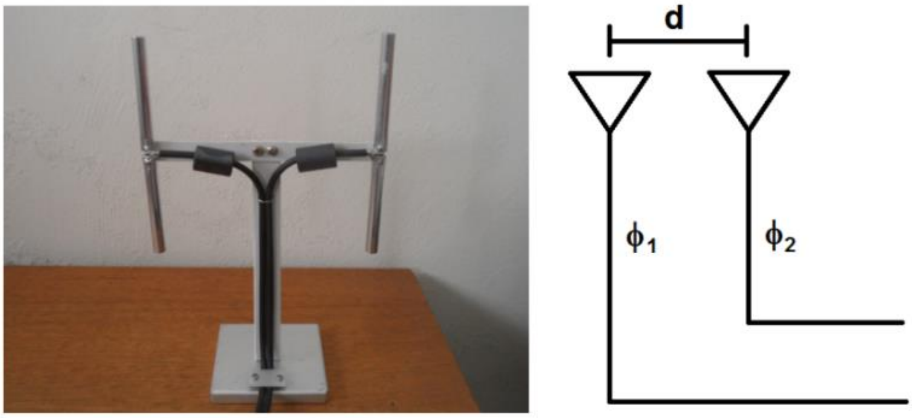

Fig. 5. Antennas for the RDF part of the system proposed.

A. The track system

Since the mobile stations in a cellular network are constantly in motion, determining their position in the network is of utmost importance. The more precise the determination of the position, the more accurate the prediction of the cell change, reducing the traffic in the backhaul. In order to get the position of the mobile station, this work proposes the use of two antennas with the same characteristics mounted to avoid interfere between each other. The suggested irradiation diagram is shown in *Fig.*6, for the practical measurement it was used dipoles as shown in *Fig.* 5 considering irradiation only from 0º to 180º.

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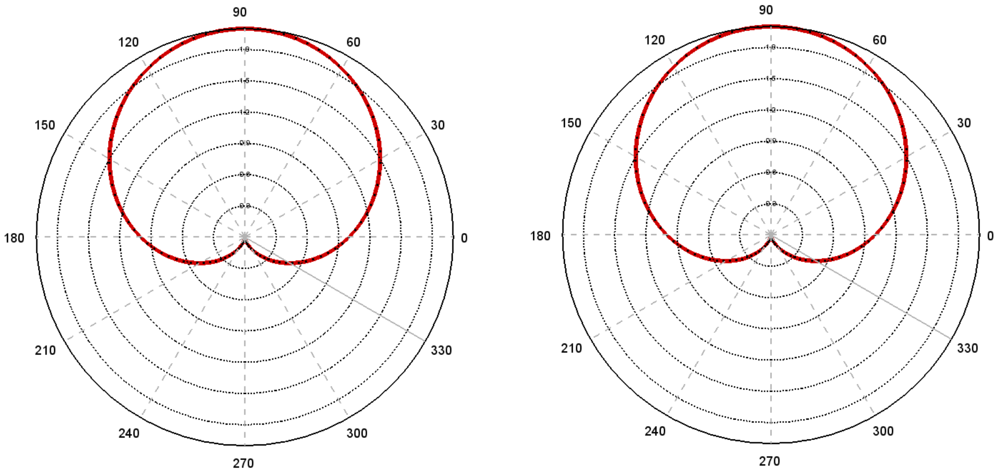

Fig. 6. Antennas diagram.

The incoming signals in each antenna can be mathematically described as:

$$E_1 = E_o e^{i(\omega t - \beta r_1)}.f(\Theta_d, \phi_d)$$
$$E_2 = E_o e^{i(\omega t - \beta r_2)}.f(\Theta_d, \phi_d) \quad (1)$$

Where $f(\Theta_d, \phi_d)$ is a function that describes the diagram of each element. When the mobile station is positioned in front of the antennas in a line perpendicular to the plane of the antennas ($\Theta = 90^o$) the signals arrive in phase. Both signals have the same amplitude and the phase difference between them is zero. When the position of the mobile station forms another angle Θ relative to the line formed by the two antennas the phase angle is not zero, i.e., there will be a difference in the phase of the signals. *Fig.7* illustrates this situation.

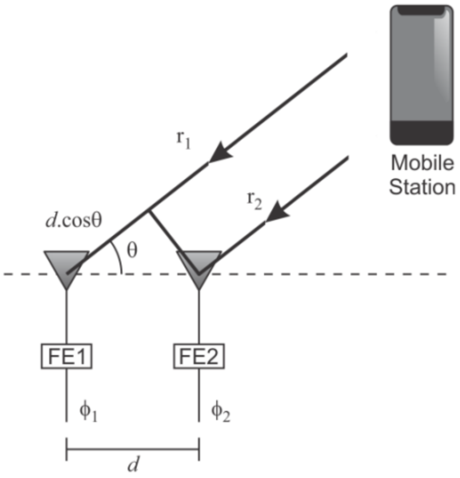

Fig. 7. Position of the mobile station and the antenna system.

The signal of the mobile station that arrives in Antenna 1 has a phase delay, since the distance from Antenna 1 to the mobile station r_1 is greater than the distance from Antenna 2 to the mobile station r_2.

The distance, r_1, can be determined as follows:

$$r_1 = r_2 + d\cos(\Theta) \tag{2}$$

The current induced in Antenna 2 is:

$$I_2 = I_o e^{i(\omega t-\beta r_2)}.f(\Theta_d,\phi_d) \tag{3}$$

I_o is the maximum amplitude of the current in the antenna terminal. The induced current in Antenna 1 is:

$$\begin{gathered} I_1 = k.I_o.e^{j(\omega t-\beta(r_2+d.\cos(\Theta)))}.f(\Theta_d,\phi_d) \\ I_1 = k.I_o.e^{j(\omega t)}.e^{j(-\beta r_2-\beta d\cos(\Theta))}.f(\Theta_d,\phi_d) \\ I_1 = k.I_o.e^{j(\omega t-\beta r_2)}.e^{-j(\beta d\cos(\Theta))}.f(\Theta_d,\phi_d) \\ \boldsymbol{I_1 = k.I_2.e^{-j(\beta d\,cos(\Theta))}} \end{gathered} \tag{4}$$

in which: k is an attenuation factor due to the increase in distance. The current phase difference I_1 and I_2 is $\beta.d.cos(\theta)$ and we can define the relationship of the induced current phase and the position angle of the mobile station as:

$$\begin{gathered} \phi = \phi_1 - \phi_2 \\ \boldsymbol{\phi = \beta.d.cos(\Theta)} \end{gathered} \tag{5}$$

Therefore, by measuring the current phase difference of the signals the position of the mobile station is accurately determined. In order to get the maximum resolution, the distance between antennas must be adjusted in a way that $-180 \leq \phi \leq 180$ when $-90 \leq \Theta \leq 90$.

$$\begin{gathered} -180 < \beta.d.\cos(\Theta) < 180 \\ \pi > |\beta.d.\cos(\Theta)| \end{gathered} \tag{6}$$

for the limits $cos(\Theta)=1$ and $cos(\Theta)=-1$

$$\begin{gathered} \pi = \frac{2\pi}{\lambda}.d \\ \boldsymbol{d = \frac{\lambda}{2}} \end{gathered} \tag{7}$$

this is the maximum resolution condition and the maximum permitted limit d value.

B. The beam system

In order to adjust the maximum beam to the mobile station, this work proposes antenna elements in an array or massive MIMO [22]. This structure allows increase the system gain and consequently the directivity. An array of identical dipoles in parallel excited by currents with controlled phases and amplitudes can concentrate the beam into a specific direction, producing a beamforming, as shown in *Fig.* 8 [23].

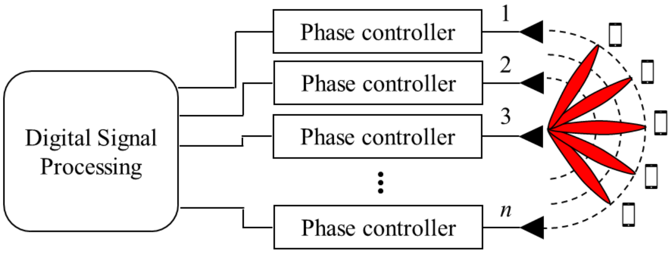

Fig. 8. Array of dipoles or massive MIMO and the irradiation direction.

If each element in the array is separated by the same distance and fed with the same current magnitude with a regular stepped increased in phase ξ, the radiation pattern is the product of the radiation pattern of the dipole and the radiation pattern of the array [24].

$$E_{total}(\Theta,\phi) = F(\Theta,\phi)\frac{\sin(Nks\cos(\Theta)+\xi)}{N\sin(ks\cos(\Theta)+\xi)} \tag{8}$$

in which: *F(Θ,ϕ)* is the dipole radiation pattern, *N* is the number of dipoles, *k* is equal 2π/λ, ξ is the stepped phase of the fed current, *s* and Θ are the distance and the angle from the antenna, respectively. Therefore, it is possible to control the signal intensity in a specific direction by adjusting the stepped phase ξ of the current in the fed points.

C. *Experimental tests*

In order to test the tracking system and prove the proposed concept, two dipoles 158 mm long, spaced at 166 mm (d=λ/2) from each other were mounted to be used as a receiver antenna system. Another dipole with the same length was used to irradiate simulating a mobile station. The toroids shown in *Fig.* 5 were used in order to minimize the common mode effect. *Fig.9* shows the complete setup used.

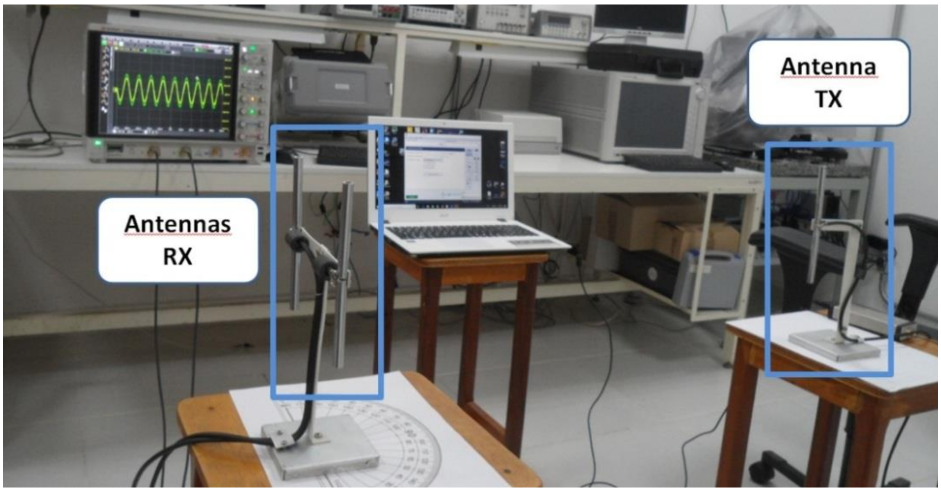

Fig. 9. Transmitter and track antennas under test.

The transmitted signal in 900 MHz was generated by the Vector Signal Generator, Signal Hound model VSG25A, and to receive the signals a High-Definition Oscilloscope Keysight model

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DSOS204A 2GHz 20GSa/s was used. For d=λ/2 in equation 5, ϕ is equal to $\pi cos(\Theta)$. The results of this scenario are summarized in Table I.

TABLE I. PHASE OF SIGNALS RELATED TO THE ANGLE OF THE MOBILE POSITION

Position Θ	**π.cos(Θ)**	**Measured**
30º	155.9º	157.8º
45º	127.3º	125.1º
60º	90º	92.4º
90º	0º	-2.4º
120º	-90º	-89.2º
135º	-127.3º	-129.4º
150º	-155º	-154.3º

As expected the angle of the position of the mobile station in relation to the plane of the received antennas system has a close relation with the difference of phase between the signals of the receiver antennas. *Fig.* 10 shows the oscilloscope screen views of the signals of both antennas with the mobile station at 60º and 90º.

Measurement	Current	Mean	Min	Max	Range (Max-Min)	Std Dev	Count
Phase(1-2)	92.40°	92.185°	91.60°	92.84°	1.25°	0.237°	87
Frequency(2)	900.53147 MHz	899.99619 MHz	898.50830 MHz	901.46235 MHz	2.9540437 MHz	631.58727 kH	88
V p-p(2)	41.4398 mV	41.4398 mV	41.4398 mV	41.4398 mV	0.0 V	0.0 V	1
V p-p(1)	90.2423 mV	90.2423 mV	90.2423 mV	90.2423 mV	0.0 V	0.0 V	1

Mobile station at 60^{o}

Measurement	Current	Mean	Min	Max	Range (Max-Min)	Std Dev	Count
Phase(1-2)	-2.45°	14.9446°	-15462.38°	63.13°	15525.51°	84.4645°	561841
Frequency(2)	900.19682 MHz	899.96028 MHz	22.498286 MHz	925.05353 MHz	902.55524 MHz	5.4332988 M	561692
V p-p(2)	58.6872 mV	55.9404 mV	4.3250 mV	94.8795 mV	90.5544 mV	10.0665 mV	64081
V p-p(1)	59.5380 mV	63.1641 mV	12.3565 mV	108.016 mV	95.6592 mV	11.7069 mV	64081

Mobile station at 90^{o}

Fig. 10. Oscilloscope screen views of received signals from Antenna 1 and Antenna 2 at the same time.

D. The multipath indetermination and triangulation

In a wide-open area without any obstacles it is relatively simple to determine the direction of a transmitter station by measuring the angles of the arriving signal in two antennas as described above. However, the presence of all kinds of different obstacles can also block and/or create other paths for the electromagnetic waves. *Fig.*11 illustrates a possible situation.

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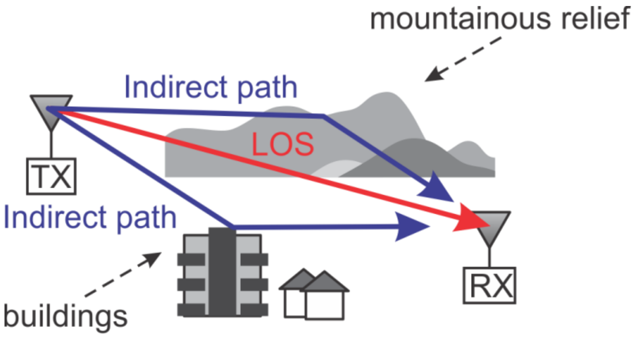

Fig. 11. The multipath effect, three signals arriving.

Since the signals propagate in different ways and different distances, signals will arrive in the receiver with the same information but with different phases. In general, the channel multipath propagation impulse response at a particular time, *t*, can be written as [25]:

$$h(t) = \sum_{i=1}^{L} a_i \xi(t - \tau_i) \tag{9}$$

in which: a_i is the signal amplitude in the path i, τ_i is the signal delay in the i-path, (i=1,...,L) is the component number of the multipath waves, and ξ(.) is the "pulse distortion" function.

It is clear that, the multi-path creates an indetermination about the position of the transmitter station, but it is possible to get some information:

- The time of arrival of the signal in the line of sight is smaller than any other signal in any indirect path.

- The strongest signal (straight line) illustrated in *Fig.*11 is the line of sight signal (LOS).

Therefore, in this situation, it is possible to determine the correct position of the transmitter even though there are signals in many paths. However, analyzing the situation illustrated in the *Fig.*12 the signal in the line of sight (LOS) is not present in the receiver, and if the angle of arrival is measured there will be a large error.

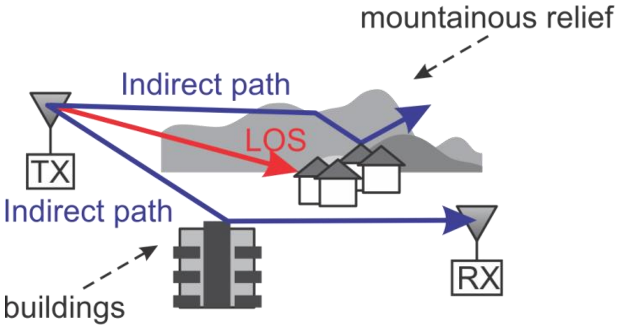

Fig. 12. The multi-path effect, only one indirect signal arriving.

To avoid this mistake, some techniques used in localization can be applied, e.g. the triangulation and the time of arrival [25]. The indetermination produced by the multi-path is a great problem to determine the exact position of a mobile station in a cell. However, if we bring this situation to the 5G and IoT world, it could be an undesirable but not a potential problem. There are some points to be considered in our proposed system:

- The main goal is to concentrate the signal in a direction to reach the mobile station, therefore, if we measure the angle of the strongest signal, that will be the best beam angle, even if the signal comes from an indirect path.
- The fact of transmit in one direction and not in all directions the total amount of signal in a cell will be reduced and, consequently, less interference the system will present.
- When multi-path is involved, the benefits of predict a change of cell and the tracking area updating initially can be impaired, but, if it is used a kind of intelligent control system, the management station can learn to control these changes. For example, if after a certain time, the signal from a mobile station arrives in a specific angle and this mobile station changes from cell A to cell C, see *Fig*. 1, the management station can "learn" about the behavior of signals in the cell and predict the tracking changes, this process can be implemented in the software using MME and eNodeB, and it should be studied further.

VI. SUMMARY AND CONCLUSIONS

This paper proposed a new concept that improves the management capacity of the Mobile Management Entity described in the Release 8 of 3GPP. This concept called tracking and beam system is capable of reducing the interference between adjacent cells, increasing the cell distance range and reducing the requested traffic in the backhaul in future networks. Based on Radio Direction Finder, this system determines the arriving signal angle from the mobile station. With this acquired information the MME can adjust the transmitter phase and beam in the direction of the mobile station. This is done for any individual channel and reduces the cells interference, because less density of signal is emitted to the cell border. In addition, the direction information improves the management capacity of the MME by predicting the handover (changing of tracking areas by the mobile station). Consequently, the requested traffic is also reduced. The improvement in the distance range is obtained due to the increase in the power in accordance with the angle of transmission, making possible the coverage area being reconfigurable by software. This paper also made a theoretical analysis in the control system by correlating the arrival angle with the difference in the induced current phases in two antennas. The results were confirmed in experimental analyses, at ϴ=30º the measured angle was 157.8º and the theoretical value is 155.9º, a value very close to the expected value.

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