Energy Saving by Base Station Pooling: A Signaling Framework

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***Abstract*—Energy consumption is among the major problems faced by cellular operators. In metropolitan areas, cellular network is divided into smaller cells due to high traffic. During low traffic period e.g., at midnight, Base Stations are underutilized but remain active and consume energy. In this paper, we propose two signaling frameworks for pooling the Base Stations of different cellular operators in a single cell during low traffic. The first Framework can be deployed rapidly with existing infrastructure. While the second framework can be used with Base Stations with enhanced capabilities. We consider cellular network with real Base Stations location in Paris region. We have taken blocking probability as Quality of Service parameter. Proposed signaling frameworks take into account call processing, subscribers soft handover between different operator's Base Station. In this way, up to 66% energy saving can be achieved for three different service providers in a single cell at low traffic period which also helps in the reduction of cellular radiation.**

***Index Terms*—Base Station pooling, blocking probability, energy saving, signaling framework, cellular system.**

I. Introduction

The use of ICT (Information and Communication Technology) should be made more efficient to reduce energy consumption and radiation. Most of the telecom operators have set energy savings as one of the evaluation parameter for their new wired and wireless infrastructure. At the same time the price of electricity has been increasing [1] and negatively impacting the operational costs of telecom companies. Therefore, reducing energy consumption has economic benefit as the wireless network operators are estimated to spend more than 10 billion dollars for electricity [2]. Recently, there has been focus on energy-efficiency in wireless networks from the perspective of reducing the potential harms to the environment caused by electromagnetic radiation [3].

In this paper, we have taken real Base Station (BS) locations of cellular networks in the Paris region via Opensignalmap [4], since these are the main energy consumers in cellular networks. Even BSs with very less activity or noactivity consumes up to 90% of their peak energy [3]. When BS of one operator is switched-off, radio coverage and services are taken care of by the other operator which remains active. The switching-off mechanism of BS must be carefully decided among operators, so as to maintain the desired quality of service (QoS) and meet radiation coverage constraints.

This paper proposes two signaling frameworks which allow BSs operated by different operators to switch-on/off depending on the traffic load experiences by each of the BS (Node B). With our frameworks, the "Billing Cycle" remains intact for each of the operator as we are pooling only the Base Stations but MSCs (Mobile Switching Center) and RNCs (Radio Network Controller) remain active. The frameworks do not need to change any existing infrastructure. Further, our proposed signaling frameworks are within the existing 3GPP standards.

This paper is organized as follows. Section II presents the Motivation for this work and related work. Section III presents framework designs. Section IV does analysis and finally Section V concludes the paper.

II. Motivation

Mobile user density is very high in metropolitan areas. Due to high traffic the region is divided into smaller cells. However, the cellular network experiences redundancy during very low traffic hours. Fig. 1 shows real location of Base Stations in Paris region. The highlighted region has approximately 20 BSs of two Operators (*Blue is Orange and Green is Bouygues Telecom*).

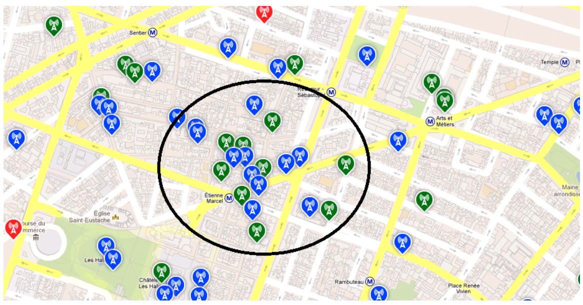

Fig. 1. Two operator's Base Stations in highlighted region in Paris [4]

Fig. 2 shows the overlapping radiation pattern of two operators' BSs.

The Fig. 3 shows cellular network if BSs of *Bouygues Telecom* are switched-off and cellular services are provided by single operator (*Orange*) in the highlighted region.

Fig. 4 shows the radiation of one operator (Orange). Even after switching-off one operator's BS, we can still cover the highlighted region. In this way we can guarantee the coverage. The user does not get any problem with signal. Hence, we can save power and decreases the radiation footprint up to $40-50\%$ during low traffic.

Therefore, if different operators pool their BSs, there can be significant energy savings by switching-off some BS in the network.

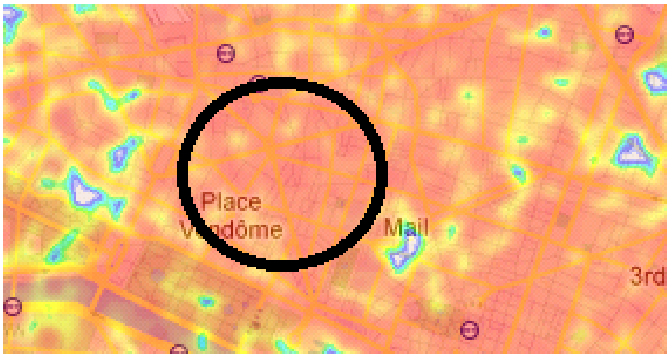

Fig. 2. Radiation pattern when two operator's Base Stations are active in highlighted region in Paris [4]

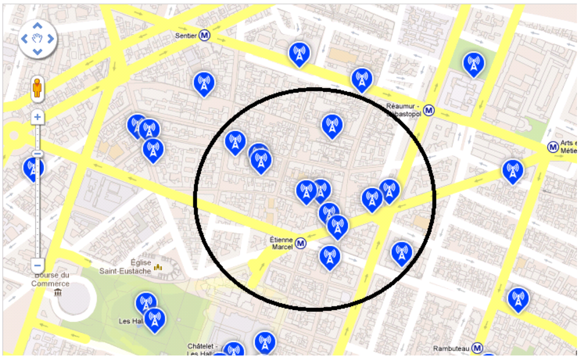

Fig. 3. Single operator's Base Stations in highlighted region in Paris [4]

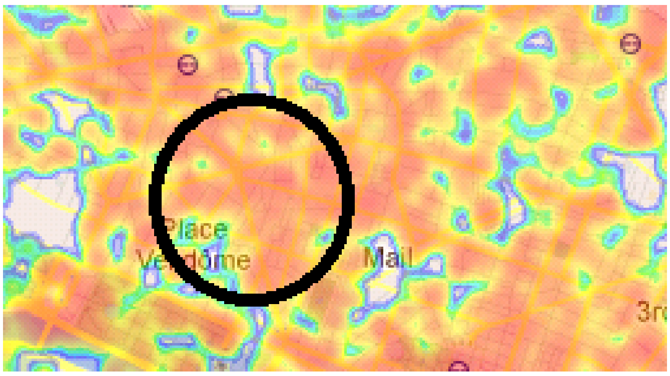

Fig. 4. Radiation pattern when only one operator's Base Stations are active in highlighted region in Paris [4]

A. *Background*

Fig. 5 shows the 3GPP UMTS architecture [5]. Here, the Iur interface is located between two RNC's and it uses the signaling and control plane over IP and ATM. This interface is used for UE (User Equipment or subscriber) soft handover from one BS (Node B) RNC to another BS RNC in a single operator. Therefore, with minor changes in signaling plane on Iur interface, connection between different operators' RNCs can be establish for switching the traffic from one operator BS to another operator BS. Hence, one operator can switch-off its BS.

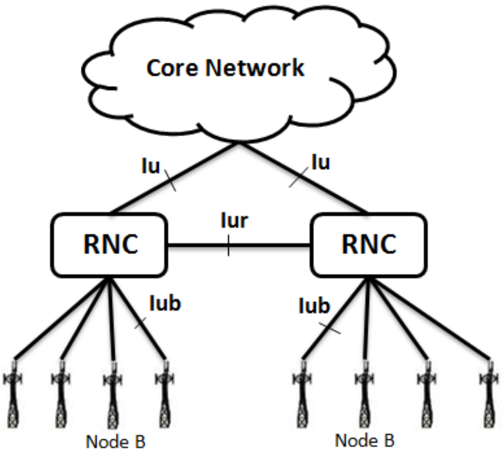

Fig. 5. UMTS architecture [5].

B. *Related Work*

There have been studies ([2], [3], [6]) which propose to share/switch-off the BSs of the same and different operators.

In [7] and 3GPP standards [8] show the RAN (Radio Access Network) sharing solutions between operators'. I.e., BS and RNC can be shared between multiple operators. In this way, frequencies and equipment pooling is done.

In [2], authors used real traffic traces and actual base station deployment map. They proposed that during low traffic in the network some BSs shut down and services provided by another active BS. So that, energy can saved.

In [3], authors developed a theoretical framework for base station energy saving that encompasses dynamic BS operation and the related problem of user association together. They explained energy saving by switched-off BS by greedy-on and greedy-off algorithms. The authors shown that total energy consumption can be reduced by up to $70-80\%$, depending on the arrival rate of traffic.

In [6] and [9], authors proposed to switch-off one base station and increase the radiation of nearby other base station of the same operator. So that it will cover the area of switched-off base station. In this way, they saved up to $30-40\%$ of energy. In [10], authors proposed energy saving in LTE BS. During low traffic BS goes into sleep mode. In [11], authors proposed to share the RNC and spectrum between two operators.

In [12], authors estimated energy saving by switching-off the base station between the operators and discuss the different energy saving solutions on operator's infrastructure.

However, none of the above work has proposed any signaling framework for pooling the BSs. We chose *Blocking Probability* as the QoS parameter according to which a BS decides to remain active or not. With our framework, the "Billing Cycle" remains intact for each of the operator as we are pooling only the BSs but MSCs and RNCs remain active. Further, the proposed signaling framework does not need to change any existing infrastructure. We do need few changes at the software level.

III. SIGNALING FRAMEWORK DESIGN

In a wireless network, Base Station is the major energy consumer [13]. Also, the dimensioning in cellular networks is driven by traffic demands, comprising a large number of small cells in metropolitan areas. According to theoretical models each operator in a single cell have their own BSs. These BSs are always switched-on. However, during low traffic (e.g., mid night), it should be possible to turn off some BSs and provided services by the fewer BSs of other operator.

For designing the framework, we began by applying the concepts of roaming for signaling framework while switching-off a BS. However, we decided against it due to the following reasons:

- Privacy Issues: Switched-off BS operator have to provide all subscribers' details to the switched-on BS operator. The operator does not like to provide its subscribers' details to another operator.
- User on call: Before soft handover, all active subscribers' details stored in home location register (HLR) have to be shared with the operator of active BS. Then, the operator of switched-off BS receives subscribers location updates from the visitor location register (VLR) of active BS operator.

Fig. 6 shows a basic theoretical model of cellular network with Seven Hexagonal cells. In every cell each operator has its own BS and all BSs are connected to RNC of the operator. We propose that during low traffic (mid night), we can switch-off all BSs of one operator and provide service via another operator. In this way, the two operators continue to offer their services while decreasing the radiations as well as their electricity costs.

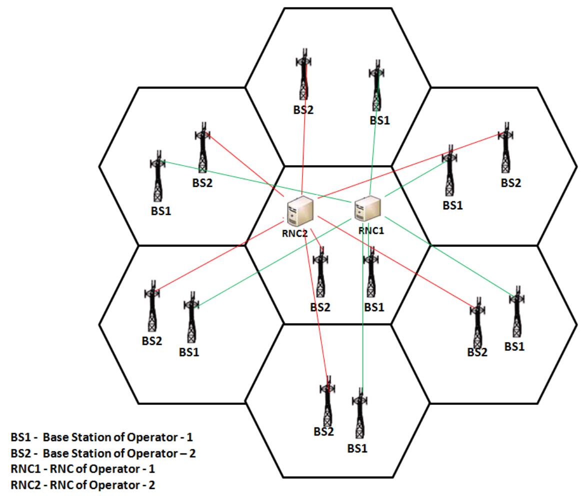

Fig. 6. Traditional cellular network

We propose to keep single active BS per cell when traffic load is below cut-off. However, in practice, BSs regions of two operators' do not overlap. So, the technique proposed by [6] for single operator can be used to compensate mismatch between the coverage area of two different operator.

For the framework, we assume following two cases for handling the subscribers while switching-off a BS:

- *Case 1:* Mobile operator 1(eg., BS1 in Fig. 6) is switched-off and its subscriber tries to place a call or it receives a call.
- *Case 2:* Mobile user is already on the call. So, the call should be seamlessly soft handover to the another RNC.

The above two cases can be dealt in two different signaling frameworks:

A. *Framework - 1*

The signaling process in this framework is implemented in two steps: 1.) Connection establishment between the RNCs and 2). Calling Process

*1) **Connection establishment between the RNCs**:* Fig. 7 shows the link establishment process. When the traffic load is below a certain cut-off (eg., 30% of the total load):

- The Base Station of Operator -1 (BS1) sends a message (*low traffic*) to the RNC of Operator -1 (RNC1).
- Then, the RNC1 sends message (*Connection request*) to RNC of Operator -2 (RNC2).
- Then, RNC2 sends *Enquire massage* to Base Station of Operator -2 (BS2).
- The BS2 checks its traffic load, if the traffic load is below the cut-off it send OK message to RNC2.
- Then, the RNC2 sends ACK to RNC1. In this way, the link is established between the two RNCs.
- Then, RNC1 sends ACK to BS1 and all users of the BS1 are soft handover [14] to BS2 through a connection between RNC1 and RNC2.
- Then, BS1 is switched-off and all new resource are allocated by BS2.

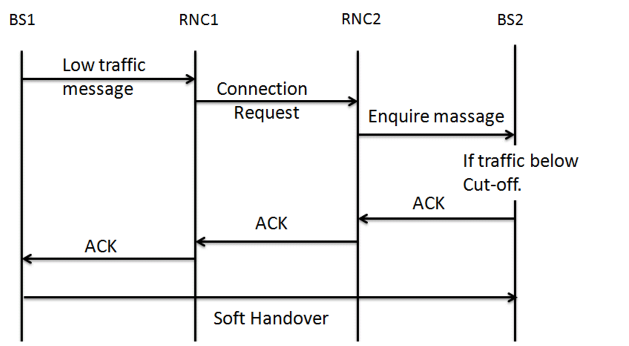

Fig. 7. Link establishment process between two RNCs for switching-off BS1.

After the switching-off BS1, the cellular network is shown in Fig. 8 where all the BS1 Fig. 6 are switched-off and connection is established between the RNC1 and RNC2.

Let us assume a scenario where there will not be many users from mid night till 6AM . Hence, plenty of resource of the Base Station remains unutilized. Therefore, BS1 should transfer its traffic to BS2. So, by switching-off BSs we can save energy. Further, we can reduce carbon footprints.

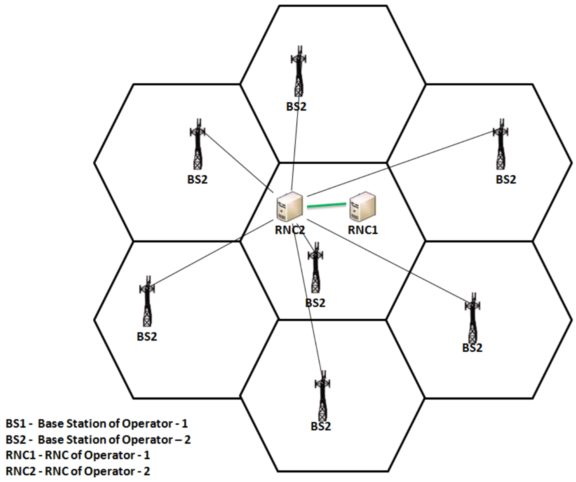

Fig. 8. Resulting Cellular network with BS2 and connection between two RNCs.

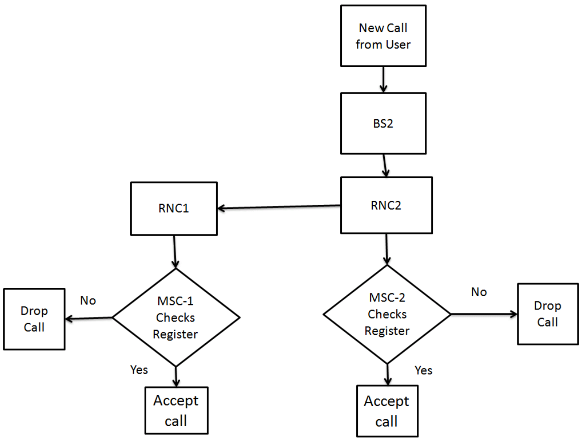

Fig. 9. Calling process after BS1 is switched-off.

*2) **Calling Process**:* Fig. 9 shows the Calling process flow chart. When the subscriber places a call, RNC2 processes the call. The RNC2 forward the call to the Mobile Switching center of Operator-2 (MSC-2) and RNC1. Mobile Switching center of Operator-1 (MSC-1) and MSC-2 both checks their registers for the subscriber details. If the subscriber details are not found in the register, the call is dropped else, the call is accepted.

*3) **Re-Switch-ON**:* After 6 AM, the BS1 is switched-on but it does not switch-on its radio. Then, BS1 stays in stand-by mode. Fig. 10 shows the procedure of switching-on the Base Station.

- When BS2 load reaches certain cut-off (eg., 70% of total load), BS2 sends (*Disconnection*) message to RNC2.
- Then, RNC2 sends switch-on message to RNC1.
- Then, RNC1 sends message (*switch-on radio*) to BS1.
- Then, BS1 sends an ACK to RNC1 and RNC1 sends an ACK to RNC2.
- After successfully exchanging ACK's, all resources and users of Operator-1 will soft handover [14] from RNC2 to RNC1.

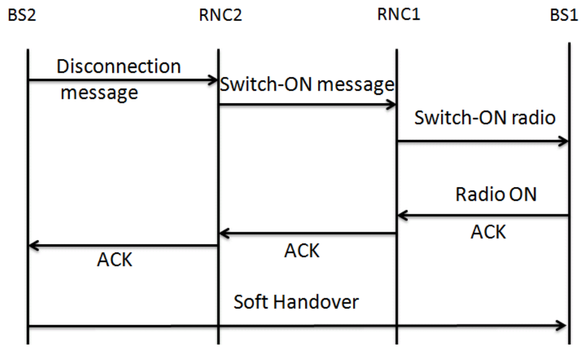

Fig. 10. BS1 switching-on process.

B. Framework - 2

The signaling process in this framework is implemented in two steps: 1.) BS connects to a another operator's RNC while remaining connected with its original Operator's RNC. 2). Calling Process.

*1) **Connection establishment between the BS and RNCs**:* Fig. 12 shows the link establishment process. When traffic load is below a certain cut-off (eg., 30% of total load):

- The BS1 sends message (*Connection request*) to BS2 in the same cell and connection request message includes the position and connection channel of RNC1. At the same time, BS1 sends (*low traffic*) message to RNC1. BS1 waits for ACK from BS2 and RNC1.
- Then, the BS2 checks traffic load. If the traffic load is below cut-off, then it sends ACK to BS1 or else it does not send any ACK.
- Then, BS2 starts authentication process with RNC1. The BS2 sends message (*authentication*) to RNC1.
- The RNC1 sends ACK to BS2.
- Then, after successful authentication, the RNC1 sends ACK to BS1. After receiving ACK from RNC1, the BS1 switches-off.
- The BS1 before switching-off, all resources and subscribers are soft handover to BS2 by RNC1.
- Fig. 11 shows the cellular networks architecture after the BS1 is switched-off.

*2) **Calling Process**:* Fig. 13 shows the Calling process flow chart. When a subscriber places a call, the call is forwarded from BS2 to RNC1 and RNC2. Both operators' MSCs checks their register for user details.If the subscriber details are not found in the register, the call is dropped else, the call is accepted.

*3) **Re-Switch-ON**:* After 6 AM, the BS1 switches-on but it does not switch-on its radio. Then, BS1 stays at stand-by mode. Fig. 14 shows the procedure of switching-on Base Station.

- When BS2 load reaches certain cut-off (eg., 70% of total load), BS2 sends (*Disconnection*) message to RNC1 and BS1.

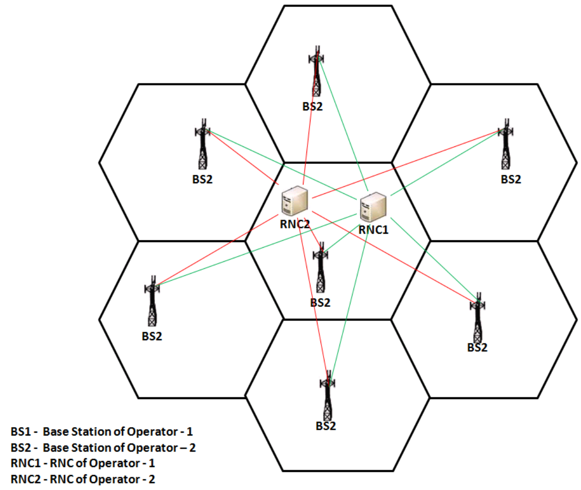

Fig. 11. Resulting cellular network (after switching-off BS1) and connection between BS2 and RNCs.

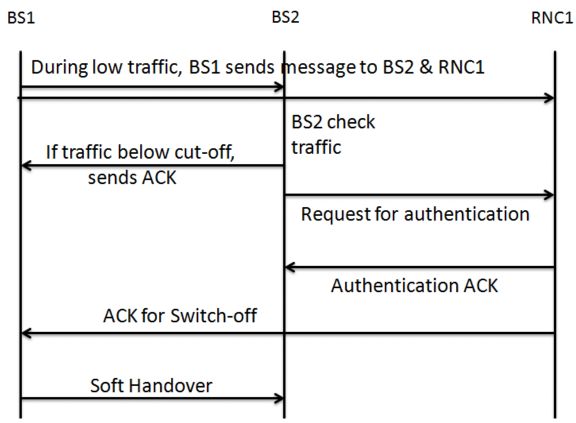

Fig. 12. Link establishment processes for switching-off BS1.

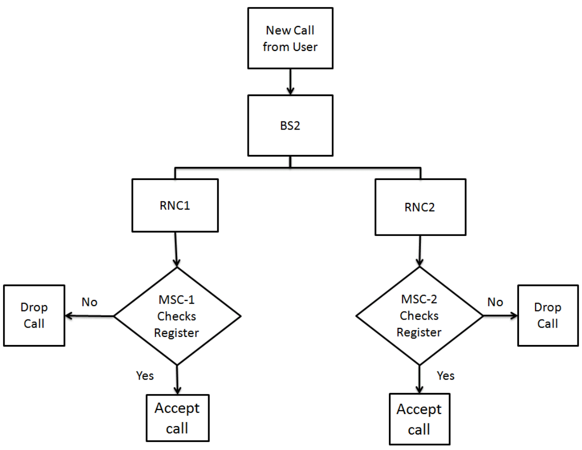

Fig. 13. Calling process after BS1 is switched-off.

- Then, RNC1 sends message (*switch-on radio*) to BS1.
- Then, after switch-on radio BS-1 sends ACK to RNC1 and BS2.
- Then, RNC1 sends ACK to BS2.

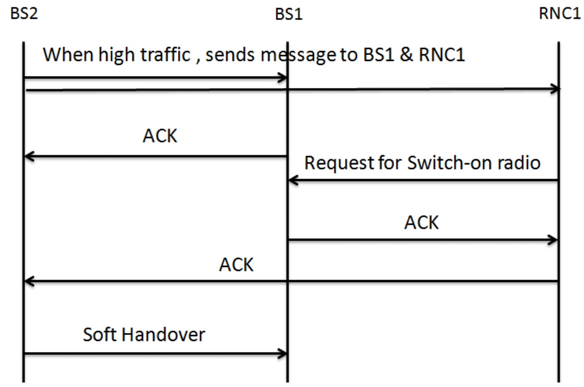

Fig. 14. Switching-on process.

- After successfully exchange of ACK's, all resources and users of Operator-1 are have soft handover [14] from BS1 to RNC1.

Framework - 1 vs Framework - 2:

Framework - 1: Connection between RNC to RNC already exists as per the 3GPP standards. So, no extra features are required in BS.

Framework - 2: It is difficult to manage one BS connecting with RNCs of two different operators. In this case, we need extra feature in BS.

When the home BS is switched-off, how subscriber selects the other Operators' BS:

In [8] and [15] explain the procedure of how a UE can select another operator's BS when the infrastructure is shared by different operators. For our case, the same procedure can be applied when UE's operator's BS is switched-off and UE selects other operator's BS. However, the selection process takes place from home operator RNC.

Subscriber's connection procedure with another operator's BS:

As per 3GPP standard [14], the home BS has the knowledge of services used by UE. Home operator's RNC (RNC1) sends message to other operator's RNC (RNC2) to provide services to RNC1's users in home BS location. The UE selection of BS2 from BS1 will be according to [14].

IV. Analysis

M/M/N/K is a widely used basic cellular traffic model to calculate the blocking probability. Let λ and μ be the arrival rate and service time respectively. Let λ arrivals according to poisson process and μ distributed according to a negative exponential probability density function with mean $1/\mu$. The system is stable if $\lambda/\mu < 1$. The system's traffic load is given as $\rho = \frac{\lambda}{\mu}$.

The Blocking Probability (P_b) is due to the full occupancy of the available channels. It is well known from queueing theory that P_b increases with the increase in traffic. Also, the traffic increases with deterioration of channel quality. One can expect that P_b increases with decreasing channel quality [16]. With m channels, the P_b can be given as :

TABLE I
RESULTING BLOCKING PROBABILITY AFTER ALL THE TRAFFIC IS SHIFTED TO SINGLE OPERATOR

Scenario	Opt-1 Traffic (Erlangs)	Opt-2 Traffic (Erlangs)	Opt-3 Traffic (Erlangs)	Total Traffic in Erlangs	P_b in %
1	22	20	30	72	0.25
2	30	25	25	80	1
3	25	27	30	82	2
4	30	30	30	90	4
5	30	32	30	92	5

$$P_b = \frac{\frac{\rho^m}{m!}}{\sum_{k=0}^{m} \frac{\rho^k}{k!}}$$

Fig. 15 shows the traffic load in terms of P_b with up to 70 channels. Here, we have used the inverse erlangb function to calculate the total traffic by P_b. With different P_b, we have an average of different traffic loads which provides traffic threshold of their respective P_b. We can see that 1% P_b system can support up to 80 Erlangs of total traffic. To provide good QoS to the subscribers P_b should not be more than 2% [17]. When some base stations are switched-off, then the active BS traffic increases during low traffic (mid night).

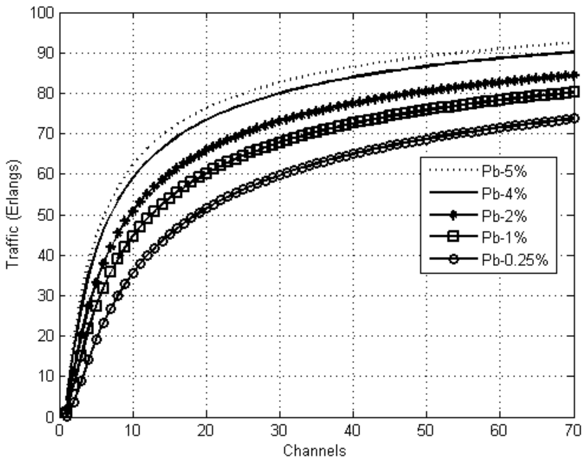

Fig. 15. Total maximum sustainable traffic load (Erlangs) based on P_b

Let us take an example with two operators' during low traffic (mid night), we assume that each BS has traffic of 30 Erlangs. With our proposed approach one operator's BS is switched-off and the subscribers are soft handover to other operator's BS as shows in Fig. 7-8. So, the active ON BS's traffic will grow to 60 Erlangs. Fig. 15 shows that the system with 0.25% P_b can support up to 72 Erlangs having 70 channels. Hence, one operator can switch-off its BS can soft handover its subscribers to other active operator's BS [17].

Table I shows 5 different scenarios with three operators along with their respective traffic in a single cell. We propose that during low traffic single BS is able to provide service for all the active users in the given cell. In *Scenario 1*, the total load in the system is 72 Erlangs. From Fig. 15, 72 Erlangs corresponds to the P_b of 0.25% for a operator with 70 channels. So, with 0.25% P_b we can guarantee the required QoS to subscribers. Similarly, in *Scenario 2* and *Scenario 3*, the total traffic for a single operator is around $80-82$ Erlangs with P_b = $1-2\%$.

TABLE II
RESULTING BLOCKING PROBABILITY WHEN TRAFFIC OF ONLY TWO OPERATORS IS MERGED

Scenario	Blocking Prob. (%) (Operator 1+2)	Blocking Prob. (%) (Operator 3)
Modified 4	0.1	0.01
Modified 5	0.1	0.01

However, if we combine the total traffic of *Scenario 4* and *Scenario 5* we get 90-92 Erlangs. If all of this traffic is serviced by a single BS, the P_b is 4-5%. This makes system highly undesirable [17]. Therefore, in this case only two operator should share their traffic. In other words, only one operators BS is switched-off and two operators remain active. Therefore, these scenarios are modified into new scenarios - *Modified-Scenario - 4, 5* as show in Table II.

For Modified-Scenario - 4 and 5, we combine Operator 1 and 2. Then, the traffic of one BS increases to $60-62$ Erlangs and the P_b is 0.1% as shown in TableII. The Operator-3 does not participate in pooling the BS and also remains active. Hence, with *Modified-Scenario - 4 (Operator 1+2)* and *Modified-Scenario - 5 (Operator 1+2)* we can guarantee the QoS to the active subscribers.

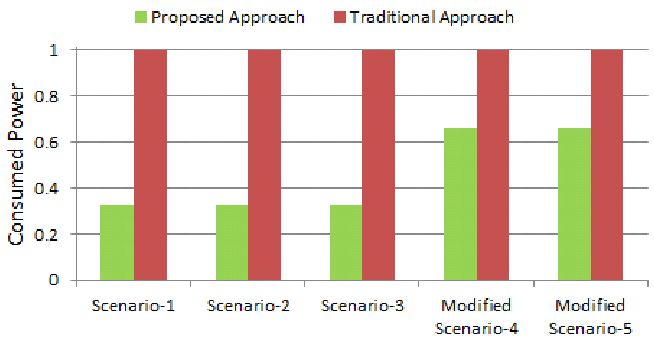

Fig. 16. Total power consumption by all active BSs in a cell for 3 operators.

We assume that all BSs consumes equal power and there are three different operators'. Fig 16 shows the power consumed with and without sharing the BS. For the Scenarios 1, 2 and 3: we need only one BS instead of three. Hence, we can save up to 66% of power during very low traffic. For the Scenarios 4 and 5: we need two BS instead of three. Even in these cases savings are up to 33%.

V. CONCLUSION

The paper proposes two signaling framework to allow different operators to share their Base Stations during very low traffic (mid night). Our two frameworks are very simple and no added infrastructure is required. The first framework can be deployed rapidly with existing infrastructure. While the second framework can be used with BSs with high capabilities. For BS sharing we used blocking probability as Quality of Service parameter. We analyzed the radiation pattern of two cellular operator's in Paris region and they were overlapping with each other. Therefore, it is feasible to provide the service even via a single operator. We show that by sharing the resources at low traffic there can be up to 66% of power saving and reduction of cellular radiation.

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