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On-off Switching and Sleep-mode Energy Management Techniques in 5G Mobile Wireless Communications – A Review

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Abstract: 5G Heterogeneous network is characterized with small cells in close proximity with one another which in most cases are active even at low traffic load periods. Such scenarios lead to unnecessary large energy consumption and co-frequency interference. This large energy consumption and interference in 5G heterogeneous networks have been an issue widely discussed in several technical literature. Different and attractive techniques on energy management have been investigated and proposed. All these have been in seeking ways of minimizing or reducing energy consumption in mobile networks. In this study the on/off and sleep-mode schemes as energy management techniques have been reviewed with the major aim of identifying weak areas of both techniques and suggesting ways which will be useful for further research works in the future. In doing so recent literature on the subject matter were consulted. The on/off and sleep-mode schemes involve switching processes which result to loss of data and information during change of state. Quality of service issues arising from incomplete or proper switching process and unnecessary delay perceived by the users were observed as major concern for both schemes. For further work, amongst other suggestions, it is suggested that the time needed between system switching command and switching operations be considered as an important factor in eliminating switching problems which will positively affect the overall quality of service.

Index Terms: Femtocell, 5G HetNeT, On/Off switching, Sleep-mode, Small cell

1. Introduction

One major form of information transmission in the world today is by wireless mobile communication. The ever increasing demand for bandwidth service in wireless networks is getting higher and higher in our everyday life. This high demand for data traffic has consequently led to tremendous growth, pushing system designers towards exploring different strategies in meeting the challenges experienced as a result of growth in the industry from one generation to the other. Today in several countries, the fourth generation (4G) network is yet to be fully deployed while others are preparing to embrace the next generation wireless network – the 5G heterogeneous network (HetNets).

The 5G compared to 4G will have the capacity to support about 10,000 times more data traffic with more than 1000 times data downloading, and the future internet will run on Ultra High Spectrum Band [1]. Focus will be shifted towards meeting such requirements like enhancing the spectral efficiency, link capacity improvement, coverage improvement, solving latency problem and providing interference solutions.

It is also understood that with the advent of 5G, there will be an emergence and increase in the number of sophisticated wireless devices or user equipment (UE) making demand on the available bandwidth. This will bring about serious challenges in terms of how to increase system capacity, enlarge the energy efficiency (EE) and boost the network data rates. It is believed that in the 5G era, there will be an increase in the number of linked 5G devices which will be about 100 times more than that of 4G, and the data rates will attain speeds up to 10 Gbps [2, 3]. 5G network performance has a lot to do with the application of millimeter wave (mm-wave) which will be the operational frequency band, massive multiple-input multiple-output (massive MIMO) antenna structure and small cells (SCs) that are in close proximity with one another [4, 5]. Small Cells in 5G HetNets are made up of femtocells, picocells and relay nodes. The SCs are densely deployed for effective improvement of network coverage, especially in indoor and urban areas [6].

Apart from SCs, there are also Macro cells (MCs) in 5G HetNets. To meet with the demand increase for higher data rates in 5G HetNets, MCs densification with SCs presents a promising solutions to the problem of increase high data rates but these densely SCs due to their closeness and increased power consumption have caused some challenges for the 5G HetNets [6]. Some of these challenges despite the huge merits of the densely deployed SCs are the large power consumption of the SCs and the interference between them [7].

A typical coverage area of MCs and SC base stations (BS) uses the same frequency spectrum. As will be expected, this frequency reuse causes interference arising from the use of the same radio frequency (RF). This form of interference caused by user equipment (UE) using the same radio resources is called inter-cell-interference (ICI) and greatly affects system performance negatively. Apart from system performance ICI also negatively affects cell-edge UEs throughput and network capacity, thus lowering the overall network quality of service (QoS).

Energy consumption in mobile communication network infrastructure has been an area of research as it concerns global climate change as well as its economic effect on the mobile Operators. The more the SCs the higher the level of energy consumption. Many researchers from both the industry and academia have been seeking appropriate methods to effectively manage energy consumption in cellular network infrastructure. Energy savings if achieved will reduce the consequences high energy consumption of mobile communication infrastructure has on the environment. This review focuses on some research works in energy management in mobile communication small cells. The aim is to determine research gaps and make useful suggestions. The observations and suggestions made for further research work are the major contributions of this study.

2. Literature Review

Recently different works have been published on how to proffer solutions to the problem of large energy consumption and interference in cellular heterogeneous networks. Different and attractive strategies have been investigated and documented in several literature such as the on/off switching technique [8-12]. In contrast to the on/off technique used by many authors the soft frequency reuse (SFR) is another technique that has been investigated and proposed as an interference mitigation strategy [13,14]. Another technique adopted by some researchers is the sleep mode technique. This scheme as reported in several literature focuses on energy efficiency, interference mitigation and allows shared spectrum access to SCs, while ensuring a certain level of QoS for the MC users [15-18]. Elsewhere, authors in [19] used a technique called cell range expansion (CRE). The CRE relied on cell association where the coverage areas of SC BSs are increased by making use of cell association bias to accommodate more devices.

This study is a follow-up on the above works but concentrates on on/off switching and sleep-mode schemes as methods of energy management in SCs. Related literature on these two schemes have been studied. Based on the reviewed literature suggestions are made as areas that need further investigations.

3. On/Off Switching Technique

A typical 5G HetNet is one with a MC BS and multiple SC BSs. To maintain or guarantee availability of service over the area of coverage where the MC is always active while the SC BSs can be dynamically switched on or off based on already defined criteria. The 5G with densely deployment of SCs introduces some technical challenges amongst which are co-frequency interference among small SCs and SC-BS huge power consumption [11,20]. In a given network, the number of UEs that can be connected to the SCs vary with time. A few number of devices or UEs may be active at a particular time in the network (high traffic load) while a great number of SCs may have no or low traffic load in their area of coverage [21]. Power will be wasted if at all times the SC BSs are fully active in the network. This condition will cause a sharp drop in the power efficiency as well as causing serious interference among the SCs [22]. To improve power efficiency of the SC BSs and mitigate interference among the SCs, on/off switching scheme for SC has been investigated and proposed in several literature.

The effect of switching off MC BSs for energy efficiency (EE) of the HetNet while maintaining SC BSs active was investigated in [8]. The work by [9], was on the dynamic SC on/off switching mechanism using the MC BS to reduce the total energy consumption of the HetNet. In this study the decision for the on/off switching scheme was based on two algorithms which are:

i) an optimal location-based operation algorithm used for uniformly distributed users
ii) a suboptimal-based approach used for non-uniformly distributed users.

Turning on or off are steps used to decrease power consumption in BSs and is based on traffic load of the UEs which changes depending on time of day (busy hour) or location (densely populated areas). Based on the requirement of the QoS, the SC BS is switched on/off in relation to the increasing or decreasing traffic load requirement. Signal transmission between the BS and UEs for both the uplink and downlink in the off mode is suspended. This is because in the off mode the BS is turned off. Since the BS is off and the UEs are active the uplink information from the UEs to the BS cannot be received and processed. The uplink signals from the UEs include channel state information (CSI) and traffic load [22]. The CSI enables the BS to be aware of the environment so that they can come on at the required period.

A Base Station is turned on with the assistance of neighboring BSs [23]. In the off mode if the SC BS is turned off, the neighboring BSs keep or maintain an information concerning their respective system loads. This system load information is used by the system to decide when to switch to on mode. By this method the neighboring BSs know when and the conditions under which a BS should be switched on and then send the required information to the BS to come ON.

The on/off switching technique provides the probability of having loss of data or information during the process. To ensure QoS is being maintained and loss of data avoided a dual connectivity based seamless handover process was adopted as explained in [10]. This is to ensure that the technique does not interfere with transmission of data.

Elsewhere in [11], a scheme known as an interference contribution rate (ICR) based small cell on/off switching algorithm was proposed as another form of achieving the on/off technique in SC 5G networks. Each SC has its specific designed ICR which serves as its on/off triggering parameter. The target signal strength (TSS) of any SC is based on both the active and inactive UEs in the network. It is the summation of all the reference signal received power of all active UEs whereas the interference signal strength is the sum of the reference signal received power of inactive UEs in the network The determination of the rate of interference as it affects the network involves complex computation. Using appropriate strategies the proposed algorithm tends to eliminates this complex computation of the contribution the interference has on the SC BSs. This technique allows the proposed algorithm to identify the SC BS to be switched on or off. Based on certain criteria together with measurements made on serving signal strength of the UEs and the distribution of traffic load in the network, the decision for on/off switching procedure is taken. This procedure involves less signaling information and hence less computational complexity.

Reduction of energy consumption by making use of efficient resource allocation, transmit power allocation, and BS on/off switching was a technique developed in [12] in which their main aim was to reduce the total power consumption of the networks. The proposed scheme was achieved by the formulation of an optimization problem in which the power budget of the SC BSs and the cross-tier interference were considered. To solve the problem of high computational complexity arising from the optimal solution the authors developed a low complexity algorithm. The BS switching on/off process was implemented based on specific algorithm which was classified as switching-off and switching-on algorithms.

3.1. Switching-Off Algorithm

The decision to turn off is determined by the BS after system information such as signal strength and traffic load are periodically shared among the BSs and UEs. In [23], three parts of switching-off algorithm were proposed. These are Pre-processing state, Decision state and Post-processing state.

i) Pre-processing state: The UEs transmit to the BSs in the uplink direction. The transmitted signal carries information based on the strength of the received signal and system load. The system load is periodically shared among the neighboring BSs and/or when there is an abrupt change in system load.
ii) Decision state: Based on the received information from its UEs and neighboring BSs, each of the BSs first calculates the network impact of UEs [24]. Decision is then made to switch off the BS based on predetermined criteria. To prevent overloading of neighboring BSs when more than one BS is switched off the following steps are taken as shown in Fig 1.

    (a) A base station that is to be switched off broadcasts a notifying signal to other active base stations requesting permission to switch off. This is called RTSO (request to switching-off).
    (b) If the request is received by any of the base stations, a clear-to-switch-off (CLSO) signal is sent back to the requesting base station. The base station can only be switched off after it has received CLSO from any of the neighboring base stations otherwise it will rebroadcast RTSO until CLSO is received from any of the base stations.
    (c) The base station on receiving CLSO from any of the neighboring base stations informs other base stations that it has been cleared to off switch off. This is done by the base station transmitting confirmation to switch-off (CTSO) to the neighboring base stations. The base station after sending CTSO is then switched off.

iii) Post-processing state: This involves UEs that are being served by the BS to be switched-off. The UEs are transferred the same time to a neighboring BS that provides the second best signal strength. This procedure of group handover of UEs is discussed in [25, 26].

3.2 Switching-On Algorithm

Since a station switched-off remains off, it cannot under such state make any switch-on decision by itself while still in the off state. This is because the station does not have any information about the system's current traffic load and so has to rely on neighboring BSs before it can be switched on. Like the switched-off process it also involves three parts [23].

i) Pre-processing state: This state is based on the last state of the BS before switch-off. Given BS_1 and neighboring base stations $BS_2, BS_3 \dots \dots BS_N$, BS_2 receives CLSO from BS_1 , BS_2 now knows that BS_1 is switched off and keeps a record of hand-over traffic from BS_1 plus its own load (ie load of BS_2).

ii) Decision state: BS_2 wakes up BS_1 by sending the request to switch-on (RTSON) to BS_1 if its own system load reaches the recorded system load of BS_1 before it was turned off. That can be represented as: if $BS_{2L} \geq BS_{1L}$ then send RTSON to BS_1 which was earlier switched off.

iii) Post-processing state: BS_1 wakes up if it receives RTSON from BS_2 and then the UEs located in their serving areas are handed over to their serving BSs based on the best signal strength.

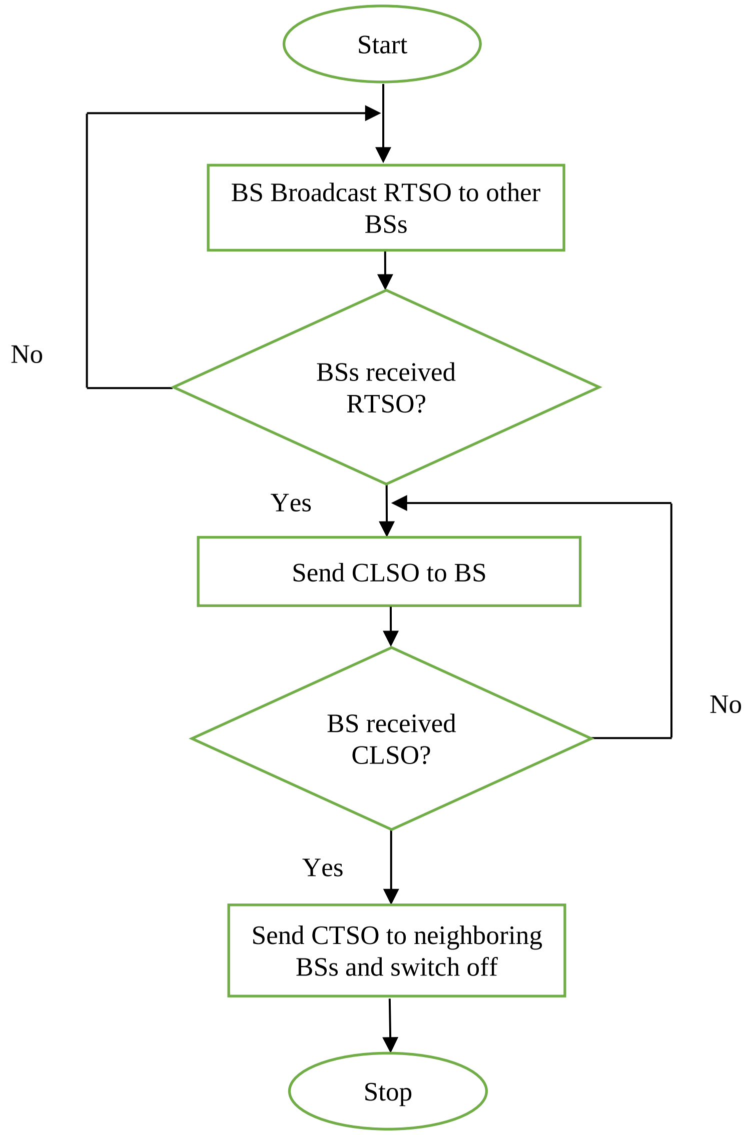

Fig. 1. Flow chart Small Cell switch-off decision criteria

4. Sleep Mode Technique

The sleep mode technique simply monitors a network and then make the decision of either switching to sleep mode or not, based on the traffic load. Unlike on/off switching scheme, sleep mode is a medium state of low power where SCs such as femtocells turn off only some of their components making easier the transition to full power state when required [2, 27]. This approach is aimed at energy saving in which some segments of the BS equipment such as power amplifiers, air conditioning systems, signal processing unit that are unnecessarily consuming power are put on sleep mode as long as necessary during off-peak hours. On the other hand an entire BS or the whole network can be switched into the sleep mode and later to active mode [28]. This approach is based on turning off components selectively [29].

Many approaches have been suggested on how sleep mode can be achieved. In [30] the sleep mode technique was employed for SCs such that decision criteria to put the SCs into the sleep mode were based on the number of users connected to the SCs. A different approach proposed in [31] made use of cell capacity ratio which was used as the decision criteria to put the SCs into sleep mode. In that study, the energy efficiency (EE) was defined as an achievable system (S_s) throughput per unit of overall power (P_a) consumption in the system and given by:

$$EE = \frac{S_S}{P_a} \quad (1)$$

Here S_s is the summation of the cell throughputs for the MCs and SCs and P_a is the overall power consumption for both MCs and SCs in active states with and without signal transmission. The overall power consumption is given by

$$P_a = N_{MB}P_{MB} + N_{ON}P_{ON} + N_{NTX}P_{NTX} + N_{SL}P_{SL} \quad (2)$$

P_{MB} is the instantaneous power consumption at the MC and assumed to be constant, N_{MB} the number of active MCs. N_{ON} is the number of SCs in the active state with signal transmission, N_{NTX} the number of SCs in active mode without signal transmission and N_{SL} the number of SCs in the sleep state. Similarly, P_{ON} is the power consumption of the SCs in the active mode with signal transmission, P_{NTX} is power consumption of the SCs in active state without signal transmission and P_{SL} is the power consumption of the SCs in the sleep state. The results obtained using computer simulation showed the proposed sleep control technique achieved better EE while keeping power consumption comparatively lower.

Energy efficiency metrics for evaluation of the performance of cellular network exist. Table 1 contains some EE metrics for BS sleep mode techniques.

Table 1. Energy efficiency metrics for BS sleep mode scheme

S/N	Metrics	Definition	Ref
1	SMS (Sleep mode savings)	$SMS = \frac{T_{Slp}}{T_{Tot}}$ The fraction of time a component or BS is in the sleep mode T_{Slp} over a given period. T_{Tot} is an approximate saving estimation at component or node level.	[32, 33]
2	Approximate Power saving estimation at component or node level	$P_{Tot} = F_{Slp}P_{Slp} + F_{Act}P_{Act}$ Where P_{Tot} is the total power consumption, F_{Slp} and F_{Act} are the fractions of time the component or BS is either in sleep or active mode, P_{Slp} and P_{Act} are the sleep and active modes power consumption, respectively.	[34]
3	ECI (Energy Consumption Index)	$ECI = \frac{p_{BS}}{KPI}$ where p_{BS} is the total input power of the BS and KPI refers to the key performance indicator. The ECI is the measure of the power utilization efficiency for a BS. A lower value of ECI indicates better energy efficiency.	**[35]**
4	P_{Rural} and P_{Urban} (Average power consumption per user or per unit area in rural and urban areas respectively)	$P_{Rural} = \frac{Total\ coverage\ Area}{Power\ consumption}$ $P_{Urban} = \frac{Number\ of\ peak\ hour\ users}{Power\ consumption}$	[36]
5	APC (Area Power consumption)	$APC = \frac{Power\ consumption}{Area}$ This is a measure of the ratio of power consumption to the area and expressed in W/km2	[37]
6	ECG (Energy consumption gain)=γ	$ECG = \gamma = \frac{Power\ consumption}{(Requested\ capacity)(Coverage\ area)}$ Expressed in $W/km^2\ bps$ For both APC and γ, lower values indicate better energy efficiency	[37]

A dense SC networks comparison of different sleep mode mechanisms was carried out in [38]. It was concluded that with proper selection of the base station, sleep mode can lead to a significant improvement in EE [38, 39].

Authors in [39] carried out a study in which they proposed a sleep mode scheme for clusters, that aim to reduce interference among femtocell users of nearby femtocells and improves the performance of MC subscribers. To validate proposed algorithm, simulations were conducted and their result showed increased data rate due to reduction in interference for femtocell users and overall cluster capacity. Also improvement in energy efficiency was gained due to reduced number of active BSs.

A strategic small cell sleeping technique was proposed in [40] as an approach to minimizing the HetNet power consumption. They concluded that range expanded SCs can be used to cover part of the sleeping SCs which are far away from the MCs and uses the MCs to serve the subscribers from the sleeping cells close to it. The authors used numerical analysis to evaluate the coverage probability as well as the power saving in a HetNet. Their results obtained confirmed the effectiveness of the scheme and showed better performance, especially with high UE density as compared with the random and conventional approaches. Elsewhere in [41], random sleeping and simulation based sleeping techniques using numerical analysis were presented.

The authors in [17] discussed on sleep control for the downlink transmission in HetNets. Their proposed technique introduced the cell capacity ratio as decision criteria that will switch the SCs into sleep mode. They concluded that the system throughput and EE performance of SCs can be enhanced by the proposed sleep control mechanism.

5. Current and Future Works

5.1 Current Works

In this study the following observations are made:

(i) Oversimplification of energy models used in some of the works involving numerical analysis may not give reliable results.
(ii) In some cases rigid assumptions were made which do not reflect real mobile communication scenarios eg not considering delays associated with switching operations and assuming that UEs are stationary at all times which is unlikely in mobile wireless communications.
(iii) The on/off switching technique provides the probability of having loss of data or information during the switching processes. This is because in the off mode the BS is turned off thus there is no transmission between the BS and UEs.
(iv) Quality of Service issues were not considered in some of the literature, eg, the uplink information from the UEs to the BS cannot be received and processed in sleep mode and the BSs may not be switched on in a timely manner. This may result to unnecessary delay perceived by the users.
(v) Various publications adopted energy saving methods with models that involved complex computations that may lead to inaccuracies in the overall results.

5.2 Future Works

Based on the reviewed literature, the following are suggestions that should be considered in future research works:

(i) Delays associated with switching operations should not be neglected. This is because of the time needed between system switching command and switching operations.
(ii) The negative impact on QoS should be given adequate consideration. This is because of the perceived loss of data and information during switching processes.
(iii) Realistic assumptions should be adopted eg considering that UEs in most cases while still active move across BSs rather than remaining at a fixed location always.

6. Conclusion

The on/off switching and sleep-mode schemes as energy management techniques in 5G heterogeneous network have been discussed. Both schemes are similar and used for energy saving in small cells but the sleep mode differ because it is a medium state of low power where SCs such as femtocells turns off only some of their components to avoid unnecessary power consumption when at low peak periods. The work also discussed some switching algorithms for on/off switching and energy efficiency metrics for sleep-mode evaluation. Based on existing literature which formed the backbone of this study, the paper achieved its main objective by identifying some research gaps. These areas that were not properly addressed are listed. The study also contains specific points as suggestions to be considered in future research work.

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