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Intelligent cooperation management of multi-radio access technology towards the green cellular networks for the twenty-twenty information society

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Abstract An unprecedented increase in subscribers and demand for high-speed data are considered a critical step towards the new era of mobile wireless networks, i.e., Fifth Generation (5G), where the legacy mobile communication system will still be operational for a long time in the future. This has subsequently increased the overall energy consumption, operational costs and carbon footprint of cellular networks, due to increase the number of base stations (BSs), which consume the most energy. Switching BSs off/on in accordance with the traffic pattern variations is considered an effective method for improving energy efficiency. However, the main concerns from the network operators are the requirements to switched on/off the BSs, coverage issues and secured the radio service for the affected area. Hence, the main focus of this study is to develop an intelligent cooperation management (switch BSs on/off) within a multi-radio access technology (RAT) environment between a future generation 5G into the existing LTE and UMTS cellular network towards green cellular networks, while guaranteeing maximum cells coverage area during a switch off session. Particle swarm optimisation has been adopted in this study to maximize the cell coverage area under the constraints of the transmission power of the BS (P_{tx}), the total antenna gain (G), the bandwidth (BW), the signal-to-interference-plus-noise ratio (SINR), and shadow fading (σ). Moreover, the modulation and coding scheme, the data rate, and the energy efficiency are considered. The results have shown that by applying the proposed a dynamic multi-RAT BSs switching off\on strategy according to the traffic load variations, the daily energy savings of up to 42.3% can be achieved, with guaranteed maximum cells coverage area.

Keywords Multiple radio access technologies · BSs cooperation · BSs switch on/off · 5G · Green networks

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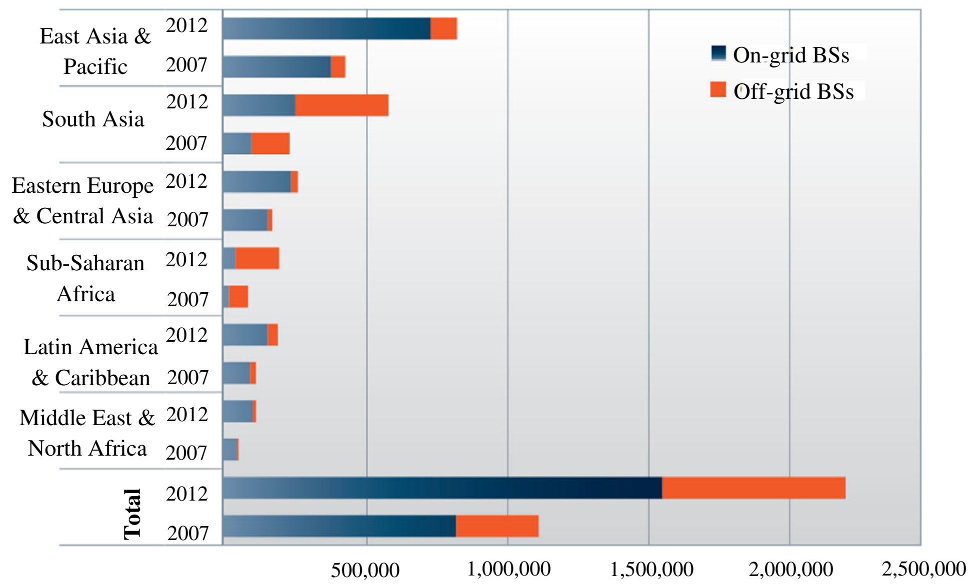
1 Introduction

The last 5 years have witnessed a tremendous development in cellular networks; wherein have become offers many data-oriented services including, but not limited to, multimedia, online gaming, and high-quality video streaming. As a consequence, both the number of mobile subscribers and the data traffic have increased explosively. However, the number of mobile subscribers constantly grows every day, where estimated 7.6 billion by 2020 and the data traffic 82 GB per subscriber per year [1], with the increase unprecedented on demand for data high bandwidth video streaming, which will represents more than half of global mobile data traffic [2]. Moreover, with the advent concept of the internet of things (IoT), it predicts that as many as 50 billion wireless devices will be connected around 2020 [3], which will lead to an exponential surge in network traffic. It is predicted that mobile data traffic will grow more than 1000 times compared with the end of 2010 beyond 2020 [4]. This unprecedented growth demands a significant increase

Fig. 1 Growth in base stations 2007–2012 [1]



of wireless network capacity. These challenges are considered a critical step towards the new era of mobile wireless networks, i.e., Fifth Generation (5G). According to the basic Shannon formula, the capacity is directly proportional to both of number of antennas and channel bandwidth, multiplied by the logarithm of the signal-to-interference-plus-noise ratio. Hence, 5G mobile wireless networks will adopt a set of new technology to support the huge increase in the volume of traffic in future wireless communications [5,6].

However, 5G mobile wireless networks are not to replacing the legacy mobile communication system but it is about enhancing and supporting them. Hence, the 2G, 3G, and 4G, will continue to evolve to provide a superior system performance [5]. Which will lead to increase both of the energy consumption and operational expenditure (OPEX), due to the significant increase in the number of base stations (BSs) that will be deployed to meet the needs of mobile subscribers, which are considered the primary source of energy consumption in cellular networks [7]. Relevant data (Fig. 1) show that the number of BSs worldwide has approximately doubled from 2007 to 2012, and the number of BSs today has reached more than 4 million [1]. With deployment 5G technology, it predicts that the number of BSs globally will grow.

From the perspective of cellular network operators, reducing electrical energy consumption is considered an economically important issue, where a significant portion of the OPEX of a cellular network goes to pay the electricity bill. For instance, it is estimated that the cellular network OPEX for electricity globally has increased more than $22 billion in 2014 [8]. In addition, energy efficiency in cellular networks is a growing concern for cellular network operators not only to maintain profitability but also to reduce the overall environment effects. It is coming to a consensus that the cellular networks sector has emerged as one of the contributors of the greenhouse gas (GHG) emission. According to [9], the amount of carbon dioxide (CO_2) that is emitted by the mobile sector expects that rising to 179 $MtCO_2$ by 2020, which represents 51% of the information and communication technologies (ICT) sector's carbon footprint.

Since the BS is a key source of energy consumption in cellular networks. In addition, dense BSs deployments today lead to small coverage area and more random traffic patterns for individual BS, which make switching BSs off\on approach more desirable to improve the energy efficiency of the cellular network [1,10]. Moreover, BSs switching off\on approach is a system-level approach that works in an area covered by multiple cells, which provide different levels of services. The aim of this study is to exploit the coexistence between the 3G, 4G, and 5G networks that are managed by a single telecommunication operator to achieve balance between network performance and energy efficiency, by a dynamic multi-RAT BSs switching off\on approach. The key contributions of this research are summarized with three basic questions: (i) when and which BSs should be switched off\on? (ii) What is the mechanism of the BSs switching scheme? (iii) What are the important parameters to consider when determining the switching status?

The rest of the paper is organized as follows. Section 2 presents the mechanism of the proposed BSs-switching scheme. The system model and the cell coverage area optimization problem are described in Sect. 3. Section 4 presents a brief introduction of the considered PSO algorithm. The simulation setup and optimization programming are given in Sect. 5. The results and discussion presents in Sect. 6, and Sect. 7 concludes the paper.

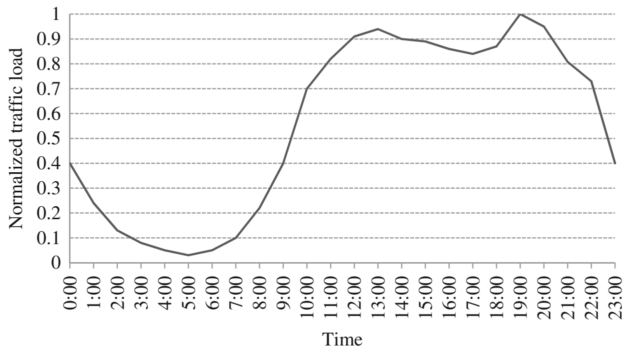


Fig. 2 The daily downlink traffic load pattern of a BS [11]

2 Mechanism of the proposed multi-RAT BSs switching scheme

This section presents an algorithm to reduce energy consumption in the multi-RAT network. We shall start with a motivational example in Fig. 2 that shows a real traffic profile from a cellular wireless access network [11]. In addition, the traffic pattern over the 5G mobile network is expected the same.

It can be observed that the traffic profile at night is much lower than during the day. Hence, the BSs are under-utilized most of the time, especially at night, which explains why energy savings can be achieved using dynamically switching on/off BSs. Fig. 3 illustrates the deployment model of radio access technologies that are considered in this study.

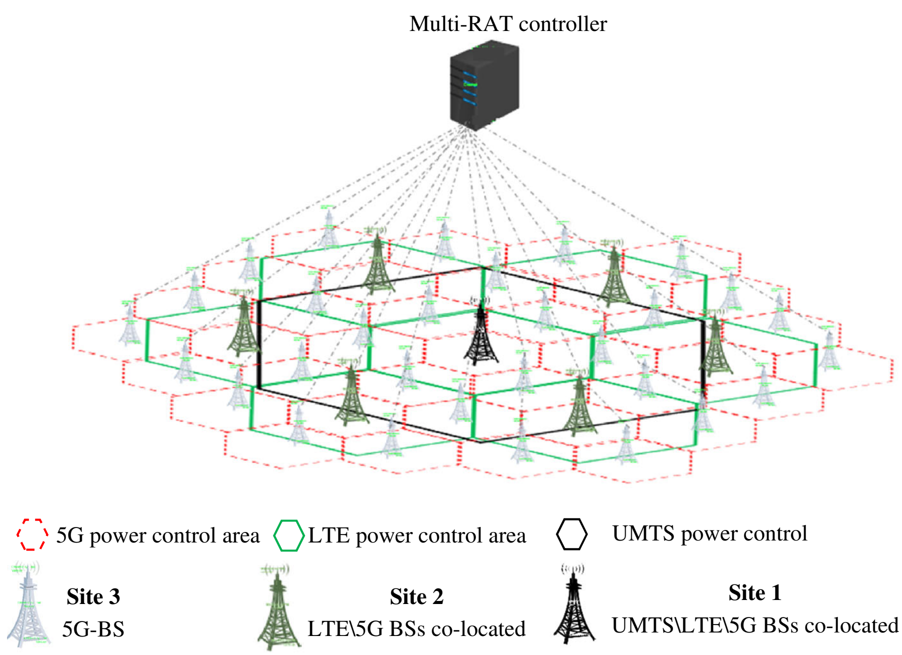
The operational on/off decision depends on three considerations: (i) fulfil the high-speed data needs of mobile subscribers at peak times; (ii) provide full radio coverage to the neighbouring cells, guaranteeing service during switch-off sessions; and (iii) switch off the largest possible number of neighbouring cells during a low traffic time, guaranteeing significant reductions in energy use. The cells that satisfy these conditions are located in the middle of a cluster and can easily provide coverage to neighbouring cells that will be switched off later. Here, three cases are considered:

2.1 Case 1: high traffic load ($0.4 < \lambda \leq 1$)

During high traffic, the mobile subscribers demand high data rate. Hence, this interval is considered as a top priority for the mobile network operators. Accordingly, in this case all BSs (UMTS, LTE, and 5G) are active and operate with full functionality to provide the best network performance and meet the needs of mobile subscribers. However, the priority will be given to the 5G mobile wireless network, which needs to adopt a set of new technology to support a high data rate and improve network capacity, and spectral efficiency in wireless mobile communications. The summary of the major milestones for evolution from 4G towards 5G is given in [6].

Along with delivering data, the 5G BSs monitor the traffic load on the mobile wireless network periodically and determines whether the 5G BSs can be turned off when the mobile traffic load drops below a certain threshold $\lambda \leq 0.4$, and stays below the threshold for a certain period (several minutes). This represents the low mobile traffic case (energy saving case).

Fig. 3 Deployment model of a hybrid topology radio access technologies. [Radius $R_{5G} = 200$ m, $R_{LTE} = 500$ m, $R_{UMTS} = 2R_{LTE} = 1$ km]



2.2 Case 2: low traffic load ($0.1 \leq \lambda \leq 0.4$)

The priority is energy saving, in which power consumption grows proportionally with the number of cells. In this case, the 5G BSs will be switched off, and service and coverage for users will be guaranteed by LTE and UMTS BSs. The 5G switching off procedures involve three steps, which is (i) pre-processing, (ii) decision, and (iii) post-processing, as shown in Fig. 4, which will be discussed as following:

2.2.1 5G BSs switching-off procedures

A. Pre-processing state the 5G BSs monitor the traffic load on the mobile wireless network periodically (e.g., every several minutes), and determines whether the 5G BSs can be turned off based on the mobile traffic load. The switching off/on decision is based on the traffic pattern. When the traffic load decrease below a certain threshold ($\lambda \leq 0.4$), and stays for a certain period (several minutes), the network will enter into a low traffic mode as to reduce the control signalling overload (switch off or on control signal) from the multi-RAT to BSs, which occupied the system BW. In this case, the 5G BSs switch-off decision is made based on the information of the 5G BSs.

B. Decision state the 5G-BSs first send a unicast control signal to a multi-RAT server,[1] which requests switching-off and only switches off when it receives a response to switching-off from the multi-RAT server. Immediately, the 5G-BSs begin to gradually decrease the radiation power of the 5G-BS. Meanwhile, UEs served by the switching-off 5G-BSs are transferred to connect with active LTE BSs and UMTS BSs based on a UE-BS signal strength path, which is a similar procedure to the conventional handover, except that a group of UEs should be handed over at the same time. There has been an abundance of research on group handover. Most of them are targeted at supporting passengers on mass transportation, such as buses or trains. The key to efficient group hand-over is to predict or prepare the handover a priori. One of the state-of-the-art group hand-over techniques, such as that of [12], could be used together with our switching off algorithm to efficiently support the group handover.

C. Post-processing state the 5G BSs switched off and listen for the wake-up control signal from the multi-RAT server. LTE and UMTS BSs are active and operate with full functionality to meet the needs of subscribers and guarantee radio service to the entire area.

However, LTE BSs are responsible for monitoring the traffic over the network. Based on the information from the LTE BSs, there are two options available, as shown in Fig. 5: (i) 5G BSs switching-on, if the traffic load increase more than 0.4 (same value at which the 5G BSs was originally switched off), and (ii) LTE BSs switching-off, which represents Case 3, idle traffic load. The following paragraphs discuss these two options.

2.2.2 5G BSs switching-on procedures

One way to implement the 5G switching-on algorithm is to reverse the switching-off algorithm. The basic concept of the switching-on algorithm is that the 5G BSs should be switched on when the system load reaches the same value at which the 5G BSs was originally switched off. However, the turned-off BSs (5G BSs) cannot make a switching-on decision because it does not have information about the current traffic load. Therefore, the switching-on process needs to rely on LTE BSs measurements for the traffic load and the multi-RAT server control signal. Similar to the switching-off algorithm, the switching-on algorithm also involves three steps as follows:

A. Pre-processing state the pre-processing state of the 5G switching-on algorithm is operated with the post-processing state of the 5G switching-off algorithm. LTE BSs are monitoring the traffic load on the mobile wireless network periodically, and determines if 5G BSs can be turned on, when the mobile traffic load increase more than a certain threshold 0.4, and stays below the threshold for a certain period, the 5G BSs switching-on decision is made, which depends on only the information of the LTE BSs.

B. Decision state the LTE BSs send unicast control signals to the multi-RAT server, which requests switching-on from 5G BSs. Immediately, the multi-RAT server sends multicast wake-up control signals to 5G BSs that switched-off. Then, the 5G BSs begin to increase their transmission power gradually and send unicast control signals to the multi-RAT server containing the response. Meanwhile, the UEs served by the LTE and UMTS BSs are transferred to active 5G BSs based on the signal strength path of the UE-BS. However, LTE and UMTS BSs are still active to support the 5G BSs and guarantee coverage and radio services, especially at the edge of the 5G cells.

C. Post-processing state the post-processing state of the switching-on algorithm becomes same of the pre-processing state of the switching-off algorithm. 5G BSs are active and monitor the mobile traffic load.

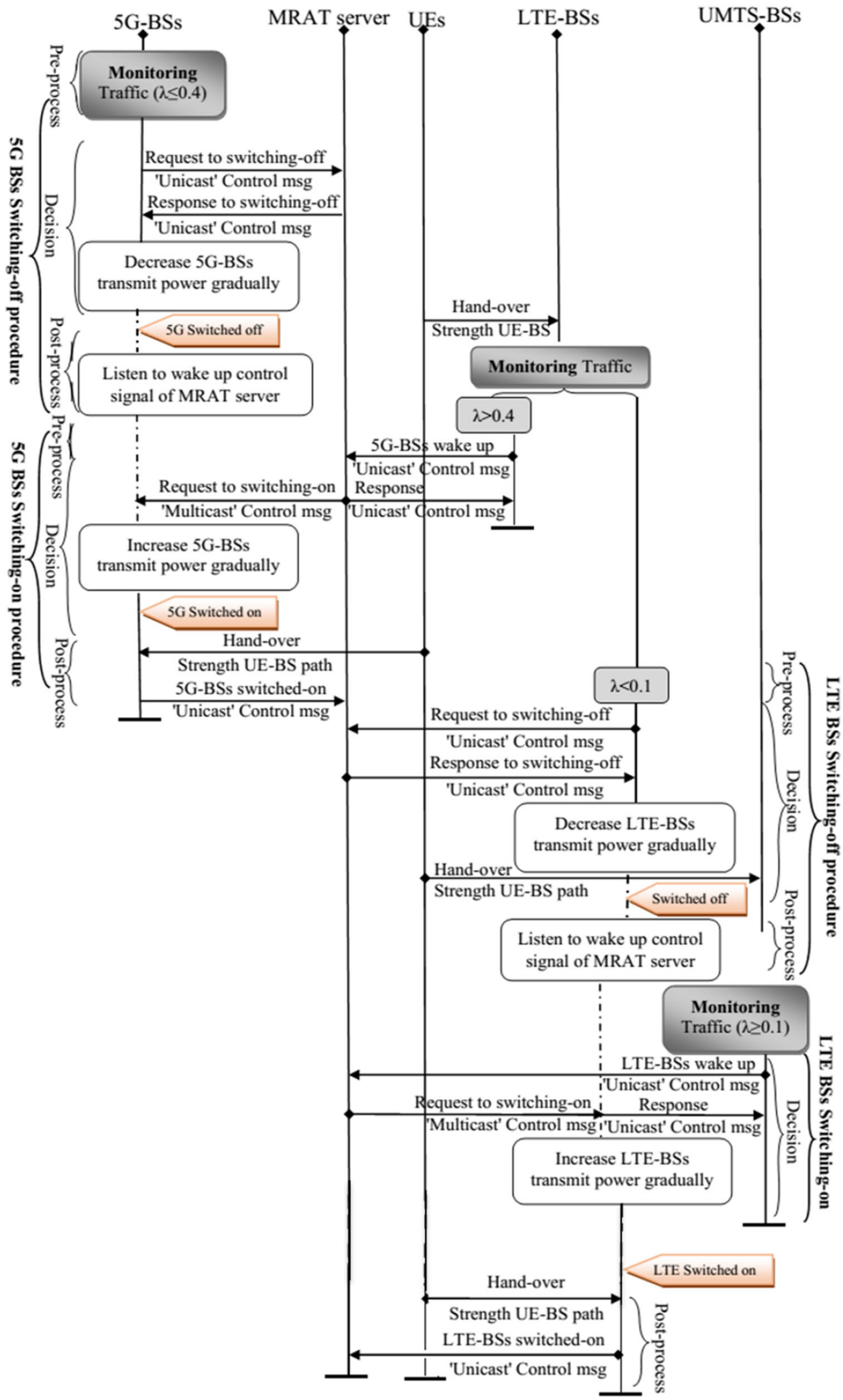
The following paragraphs are discussed the second option, switching-off LTE BSs and move to Case 3: Idle traffic load, if the traffic load became less than 0.1.

2.3 Case 3: idle traffic load ($0 < \lambda < 0.1$)

The power consumption grows proportionally with the number of cells. In this case, 5G and LTE BSs are switched

[1] The multi-RAT server act as a 'brain' for complex control, regulation and communication. In addition to the control functions, it collects and analyzes data and uses this information to make a decision; data-logger and alarm memory capabilities.

Fig. 4 Cooperative multi-RAT switching off\on procedures scheme



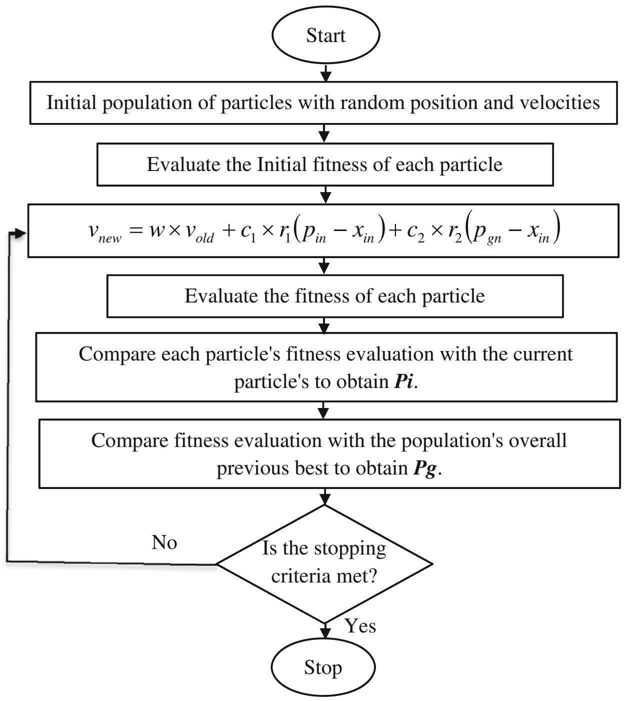


Fig. 5 Flowchart of the PSO technique

off, service and coverage for users will be guaranteed by UMTS BSs, and the specific needs of subscribers can be met using UMTS technology, which has the following features: (i) the bandwidth is 5 MHz, which provides data rates of up to 14 Mbps [13]; and (ii) high coverage area, due to that the receiver sensitivity power is low; a low-order modulation, such as quadrature phase shift keying (QPSK), is more robust and can tolerate higher levels of interference at the edge of a cell.

The LTE BSs switching off\on procedures, as shown in Fig. 5, which will be discussed as following:

2.3.1 LTE BSs switching-off algorithm

A. Pre-processing state this state is in a low traffic case, based on the mobile traffic load information of LTE BSs. LTE BSs switch-off decision is made, when the traffic load drops below a certain threshold ($\lambda < 0.1$), and stays below the threshold for a certain period.

B. Decision state the LTE BSs send a unicast control signal to a multi-RAT server, which requests switching-off and only switches off when it receives a response to switching-off from the multi-RAT server; immediately, the LTE-BSs begin gradually decreasing their transmission power. Meanwhile, UEs served by the switching-off LTE-BSs are transferred to connect with active UMTS-BSs based on a UE-BS signal strength path.

C. Post-processing state LTE BSs switched off and listen for the wake-up control signal from the multi-RAT server. UMTS-BSs are active and guarantee radio service to the entire area as well as monitoring mobile traffic load periodically, and determines if LTE BSs can be turned on, when the mobile traffic load increase more than 0.1 (same value at which the LTE BSs was originally switched off), and stays below the threshold for a certain period; LTE BSs switch-on decision is made.

2.3.2 LTE BSs switching-on algorithm

A. Pre-processing state the pre-processing state of the LTE switching-on algorithm is operated with the post-processing state of the LTE switching-off algorithm. The turned-off BSs cannot make a switching-on decision because it does not have information about the current traffic load. Therefore, the switching-on process needs to rely on UMTS BSs measurements for the traffic load and the multi-RAT server control signal.

B. Decision state the UMTS BSs send unicast control signals to the multi-RAT server, which requests switching-on from LTE BSs. Immediately, the multi-RAT server sends multicast wake-up control signals to LTE BSs that switched-off. Then, LTE BSs begin to increase their transmission power gradually and send unicast control signals to the multi-RAT server containing the response. Meanwhile, the UEs served by the UMTS BSs are transferred to active LTE BSs based on the signal strength path of the UE-BS. However, UMTS BSs are still active to support the LTE BSs and provide extra coverage.

C. Post-processing state LTE BSs are active, and delivering data as well as responsible for the monitoring the traffic over the network.

However, the main concerns of cellular network operators are coverage issues and securing radio service for cell areas that are switched off. The following Sect. 3 will highlights on the mathematical model, and problem formulation of the cell coverage area.

3 Mathematical model and problem formulation

The coverage area of BSs depends on many parameters, where the most important parameters are the surrounding environment and the maximum radius of the cell, which have a significant impact on the received signal.

3.1 Propagation model

Three phenomena primarily affect the properties of the received signal: propagation path loss, multi-path fading, and shadow fading. Therefore, a basic propagation model for the

Table 1 Switching off\on approach list of simulation parameters

Item	Parameter	Acronym	UMTS	LTE	Unit
Network parameters	Carrier frequency	f_c	2.1	2.6	GHz
	Bandwidth	BW	5	1.4–20	MHz
	Max. cell radius	R	1	0.5	Km
Base station parameters	BS transmission power	$P_{tx}^{\min} - P_{tx}^{\max}$	10–40	1–10	W
			40–46	30–40	dBm
	BS antenna height	h_{BS}	25	20	m
	Tx antenna gain	$G_{min} - G_{max}$	5–10		dB
	Number of antennas	$N_{ant.}$	2		#
	Number of sectors	$N_{sect.}$	3		#
Mobile station parameters	Thermal noise density	N_o	174		dBm/Hz
	Noise figure	N_f	9		dB
	Implementation margin	IM	3		dB
	UE antenna height	h_{UE}	1.5		m
Propagation losses	Morphology	Uurban			
	Propagation model	3GPP UMa-NLOS			
	Avg. building height	h_{bl}	20		m
	Street width	W_{st}	20		m
	SINR	SINR_{min}	−7	−5.1	dB
		SINR_{max}	20	17	
	Shadow fading margin	σ	4–8		dB
	Exponent path loss	α	3.2		#

received power (P_{rx}) can be written as follows [14]:

$$P_{rx} = P_{tx} + G - P_L - \sigma, \tag{1}$$

where P_{tx} and G denote the transmitted power and the total antenna gain, respectively; P_L represents the path loss model; and σ is the shadow fading margin.

Third generation partnership project urban macro (UMa) non-line of sight (NLOS) propagation model ifor the channels between BSs and UEs is considered in this study [15]. The 3GPP UMa-NLOS path loss model is expressed as a function that includes the frequency (f) in GHz, BS antenna height (h_{BS}) in meter, UE antenna height (h_{UE}) in meter, average building height (h) in meter, street width (w) in meter, and radius of the cell (R) in meter, as following in the next formula,

$$\begin{aligned} P_L = {} & 161.04 - 7.1\, Log_{10}(w) + 7.5\, Log_{10}(h) \\ & - \left(24.37 - 3.7\left(\frac{h}{h_{BS}}\right)^2\right) \\ & \times Log_{10}(h_{BS}) + (43.42 - 3.1\, Log_{10}(h_{BS})) \\ & \times (Log_{10}(R_m) - 3) + 20\, Log_{10}(f_{GHz}) \\ & -(3.2\,(Log_{10}(11.75 h_{UE}))^2 - 4.97) \end{aligned} \tag{2}$$

The cell coverage area in a cellular system is defined as the percentage of the area within a cell that has received a signal from a power above a given minimum $P_{\min}$. A cell requires some minimum received SINR for acceptable performance; the *SNIR* requirement translates to a minimum $P_{\min}$ throughout the cell. The transmission power at the base station is designed for an average received power at the cell boundary of $P_{\min}$. However, random shadowing and path loss will cause some locations within the cell to have received power below P_{min}. According to [16], the minimum received power P_{min} can be expressed as follows:

$$P_{\min} = N_o Bw + N_f + \mathrm{SINR} + \mathrm{IM} \tag{3}$$

where N_o BW represents the thermal noise level for a specified noise bandwidth, N_f is the noise figure for the receiver, and IM is the implementation margin.

3.2 Cell coverage and problem formulation

The closed form for the cell coverage can be expressed as follows [17]:

$$C = Q(a) + \exp\left(\frac{2 - 2ab}{b^2}\right) Q\left(\frac{2 - ab}{b}\right) \tag{4}$$

Fig. 6 Pseudocode of the considered PSO algorithm

Algorithm of the proposed scheme

```
1:  Initialize PSO parameters, Number of particles (N= 20), Learning factors (c1= c2= 2),
    Dimension of particles (D= 5), Stopping condition (Iter. = 50), Initial weight (wmax= 0.9), &
    Final weight (wmin=0.4).
2:  Initial populations of particles Xi = (Ptx, G, BW, SINR, σ) with random positions and zero
    velocities Vi.
3:  Comparing the position of each particle with constrains
4:    if (Xi > max. constrains) then
5:      Xi = max. constrains
6:    end if
7:    if (Xi < min. constrains) then
8:      Xi = min. constrains
9:    end if
10: Evaluate the initial fitness values f (Xi) of each particle according to Eq. (6),
11: Store the best initial fitness value and both of Pbest (Pi) and Gbest (Pg).
12:   while i< iter do
13:     r1 = rand (); r2 = rand ();
14:     Calculate w according to Eq. (14),
15:     Update Vi according to Eq. (12),
16:     Update Xi according to Eq. (13),
17:     Comparing the position of each particle with  constrains
18:     Repeat steps 3 – 9
19:     Evaluate a new fitness values f (Xi) of each particle
20:     Compare each particle's fitness evaluation with the current particle's to obtain the
        individual best position
21:     Compare fitness evaluation with the population's overall previous best to obtain the
        global best position
22:   end while
23: Given optimal solution best global fitness (Max. coverage) and the best global position (Ptx,
    G, BW, SINR, σ).
```

$$a = \left(\frac{P_{\min} - P_{rx}(r)}{\sigma}\right), \quad b = \left(\frac{10\alpha \log_{10}(\exp)}{\sigma}\right), \tag{5}$$

where σ is the standard deviation of the shadow fading and α is a path loss exponent. Cell coverage area is expressed as a function $C = f(a, b) = f(P_{\min}, P_{rx}, \alpha, \sigma_{\varphi})$, where the minimum received power is expressed as a function $P_{\min} = f(N_o, \text{BW}, N_f, \text{SINR}, \text{IM})$ and the received power is $P_{rx} = f(P_{tx}, G, L, \sigma)$. The problem formulation is described as follows:

$$(p:) \quad \underset{Ptx,G,BW,SINR,\sigma}{\text{maximize}} \times \left[Q(a) + \exp\left(\frac{2-2ab}{b^2}\right) Q\left(\frac{2-ab}{b}\right)\right] \tag{6}$$

which is subject to the following constraints:

$$0 < P_{tx} \le P_{tx}^{\max} \tag{7}$$

$$G_{\min} \le G \le G_{\max} \tag{8}$$

$$BW_{\min} \le BW \le BW_{\max} \tag{9}$$

$$SINR_{\min} \le SINR \le SINR_{\max} \tag{10}$$

$$\sigma_{\min} \le \sigma \le \sigma_{\max}. \tag{11}$$

The problem posed in Eq. (6) is a nonlinear optimization problem. PSO has been adopted in this study to maximize the cell coverage area under constraints for the P_{tx}, BW, G, SINR, and the σ. Moreover, the MCS, the data rate, and the EE are considered. The most significant advantages of using PSO approach are not only it is flexible and adaptive to the problems, but also it has strong global search ability and robust performance. PSO performance is comparable to other optimization techniques, such as the genetic algorithm or ant colony algorithm since it is faster and less complicated; it has also successfully been applied to a wide variety of problems. Moreover, PSO is simpler to implement and very efficient global optimizer for continuous variable problems [18].

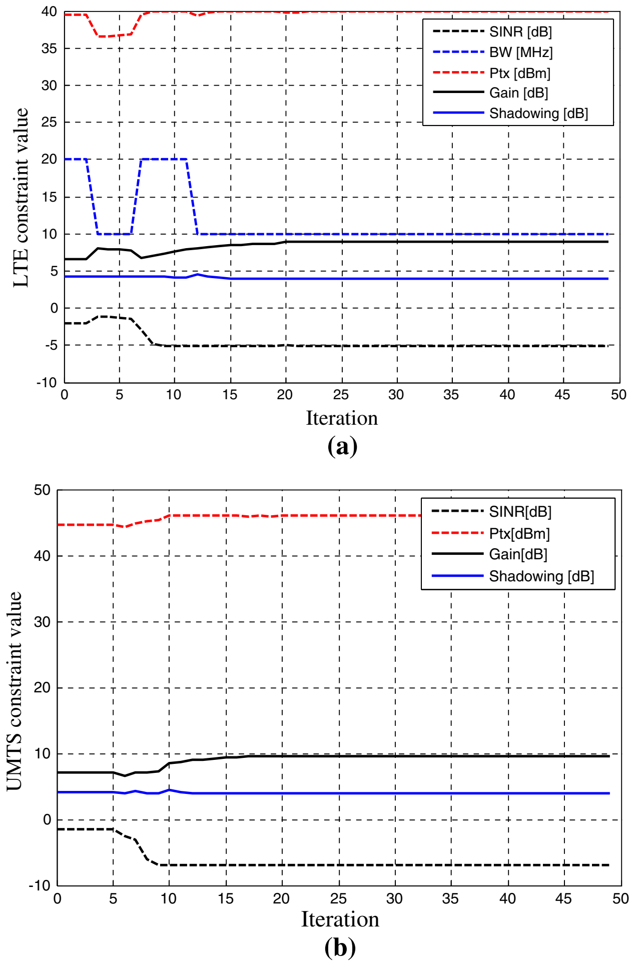


Fig. 7 The behaviour of the constraint parameters that impact the cell coverage. **a** Optimum constraints for LTE BS, **b** optimum constraints for UMTS BS

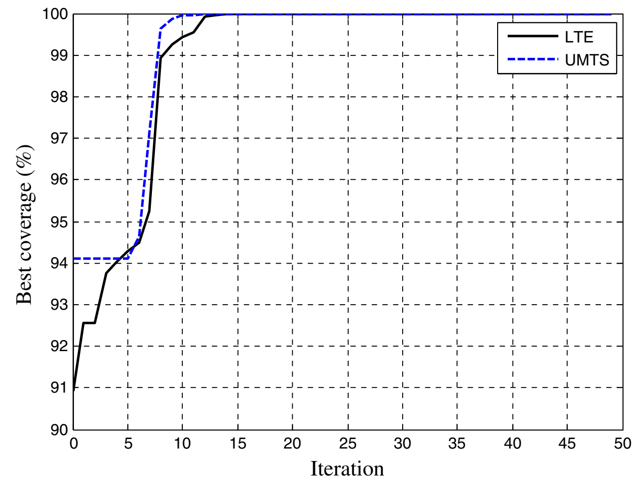


Fig. 8 The behaviour of fitness function—coverage with respect to the constraint parameters

4 Bio-inspired particle swarm optimisation algorithm

The PSO algorithm was proposed by Kennedy and Eberhart in 1995 [19]. The particles cooperate to search for the global optimum in an N-dimension hyperspace. The current status of each particle i is denoted by a velocity vector $\boldsymbol{V_i} = [v_{i1}, v_{i2}, ..., v_{iN}]$ and a position vector $\boldsymbol{X_i} = [x_{i1}, x_{i2}, ..., x_{iN}]$. Moreover, the particle i will keep a vector $\boldsymbol{Pbest_i} = [p_{i1}, p_{i2}, ..., p_{iN}]$ to store its personal historically best position found so far, that is, the position with the best fitness value that the particle has found. The best one of all the $\boldsymbol{Pbest_i}$ in the whole population is regarded as $\boldsymbol{Gbest} = [g_1, g_2, ..., g_N]$. In the process of the PSO algorithm, the $\boldsymbol{V_i}$ and $\boldsymbol{X_i}$ are initialized randomly and are updated as Eqs. (12) and (13) generation by the guidance of $\boldsymbol{Pbest_i}$ and $\boldsymbol{Gbest}$.

$$v_{new} = w \times v_{old} + c_1 \times r_{1j}\left(p_{ij} - x_{ij}\right) + c_2 \times r_{2j}\left(g_j - x_{ij}\right), \tag{12}$$

$$x_{ij\_new} = x_{ij\_old} + v_{new} \tag{13}$$

The c_1 and c_2 are acceleration coefficients, which are commonly set as 2, or can be adaptively controlled according to different evolutionary states. The r_{1j} and r_{2j} are two randomly generated values in range [0, 1] for the jth dimension [18]. The w is the inertia weight, which is computed as following:

$$w = \frac{w_{\max} - [(w_{\max} - w_{\min}) \times iter]}{iter_{\max}}, \tag{14}$$

where w_{max} is the initial weight, usually chosen as a large value but less than 1; w_{min} is the final weight; $iter$ is the current iteration number; and $iter_{max}$ is the maximum iteration number. A large w enables a global search, whereas a small w enables a local search. Linearly decreasing the inertia weight from a relatively large value to a small value through the course of the PSO run gives the best PSO performance comparisons with fixed inertia weight settings. Figure 5 summarises the PSO algorithm process.

5 Simulation setup and optimization programming

The simulation layout is based on the multi-RAT network environment as given Fig. 3. The network consists of a one UMTS, 7 LTE, and 49 5G BSs, which are managed by a single multi-RAT server. During low traffic load, 5G BSs are switched, service and coverage will be guaranteed by LTE and UMTS BSs. While, during idle traffic load, both of

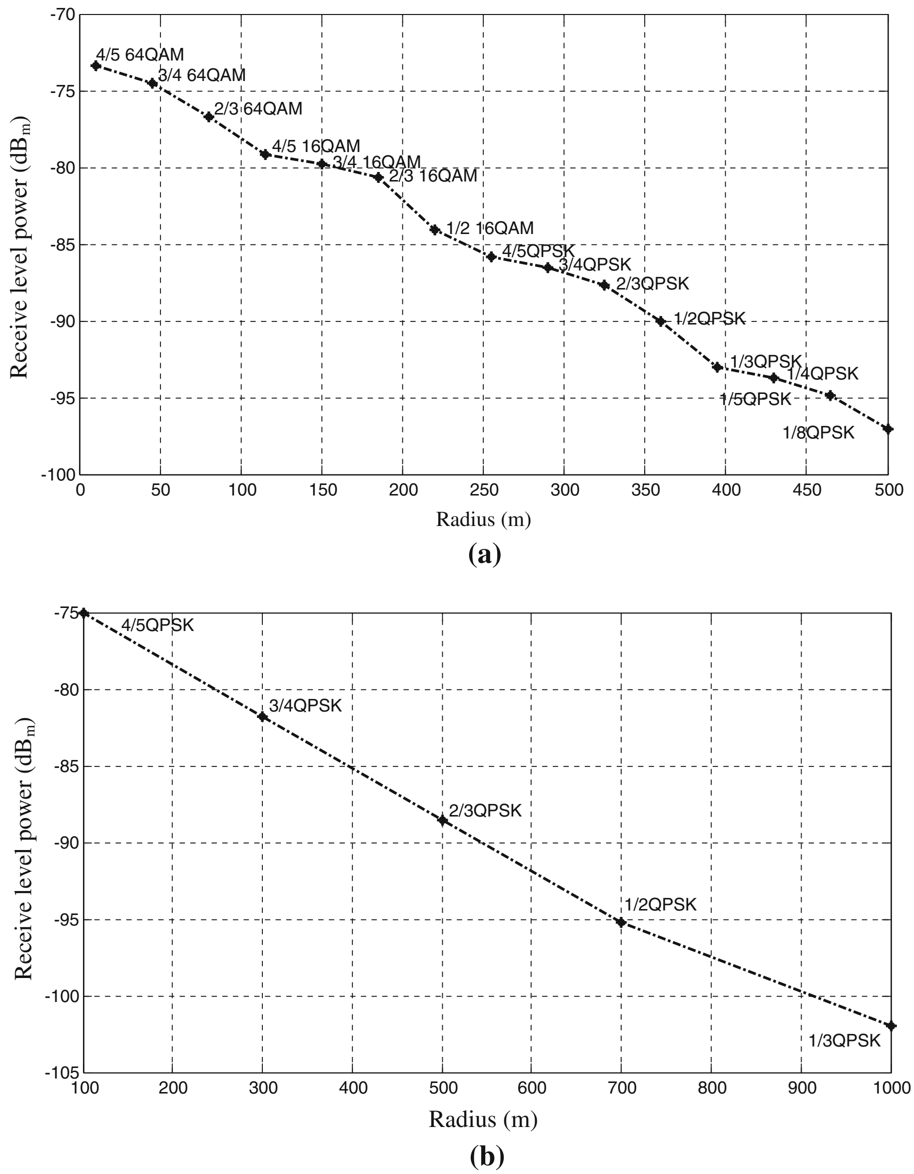


Fig. 9 Cell radii versus receiver sensitivity power for different MCSs. **a** LTE with $P_{tx} = 40\,\mathrm{dB_m}$ and BW = 10 MHz, **b** UMTS with $P_{tx} = 46\,\mathrm{dB_m}$ and BW = 5 MHz

the 5G and LTE BSs are switched, coverage will be guaranteed by UMTS BSs. The PSO approach is implemented and evaluated to maximizing cell coverage area (LTE and UMTS) during a switched off session, under constraints of the P_{tx}, BW, G, *SINR*, and the σ. The maximum transmission power of BS $P_{tx}^{\max}$ depends on the radius of coverage and the signal propagation fading. To simplify the model derivation, the macro BS transmission power is normalized as $P_o = 40\,\mathrm{W}$ with the coverage radius $R_o = 1\,\mathrm{km}$. Similarly, the $P_{tx}^{\max}$ with coverage radius R is denoted by $P_{tx}^{\max} = P_o \times (R/R_o)^{\alpha}$ [20,21]. Thus, LTE maximum cell radius was 0.5 km and $P_{tx}^{\max}$10 W; while the UMTS maximum cell radius was 1 km with $P_{tx}^{\max}$40 W. More details of the simulation parameters are given in Table 1.

The parameter configurations and the pseudocode of the PSO algorithm are presented in Fig. 6. The dimension of particles D is 5, the number of particles N is 40, the acceleration coefficients c_1 and c_2 are both 2.0, the stopping condition *iter.* is 50, the initial weight w_{max} is 0.9, and the final weight w_{min} is 0.4. In addition, the initial populations of particles $X_i = (P_{tx}, G, BW, SINR, \sigma)$.

6 Results and discussions

The dense BSs deployments which have been designed to serve during peak traffic leads to wastage of energy during low traffic hours. Due to that, BSs consumes the highest proportion of energy in cellular networks, which make switch off\on approach more desirable. The basic idea is when some BSs are switched off, radio coverage and service provisioning are assumed to be taken care of by the stations that remain active. In this way, service is guaranteed to be available over the entire service area at all times. However, switch off\on approach should follow certain design principles. The coverage area of BSs, and propagation environment along with energy consumption are the main elements that should be taken into account for implementation and evaluation. The PSO has been adopted to maximize the LTE and UMTS cell coverage area during switch off session under five different constraints: (i) the P_{tx}; (ii) the total antenna gain G; (iii) the flexible *BW* (only applicable in LTE, not supported in UMTS); (iv) the *SINR*; and (v) shadow fading, σ. The impact of these parameters on the cell coverage area is shown in Fig. 7.

P_{tx} and G are considered the most important parameters for maintaining coverage at the edge of a cell, where the SINR is low and the shadowing is high. When these parameters increase, the coverage also increases, as shown in Fig. 8.

At initial with random particle positions and zero velocities, the UMTS cell coverage area was 94.11%, with $P_{tx} = 44.61\,\mathrm{dB_m}$ and $G = 7.07\,\mathrm{dB}$, at SINR= -1.58 dB and $\sigma = 4.16$ dB. As for LTE BS the coverage was 90.91% with $P_{tx} = 39.59\,\mathrm{dB_m}$, $G = 6.60\,\mathrm{dB}$, SINR $= -2.07\,\mathrm{dB}$, and $\sigma = 4.24$ dB, as shown in Fig. 7. Then, a swarm intelligence (SI) algorithm that has strong global search ability, begin a search on the optimum input parameters that will be achieved the maximum coverage, when the σ high and SINR low. From Fig. 7 when the SINR decreased both of the P_{tx} and G are increased to maintain the maximum coverage area, as shown in Fig. 8. The simulation results have shown that the optimum parameters that maintain maximum coverage at the edge of the cell are $P_{tx} = 46\,\mathrm{dB_m}$ and $G = 8.96$ dB, at SINR $= -7$ dB and $\sigma = 4$ dB for UMTS cells. The $P_{tx} = 39.91\,\mathrm{dB_m}$ and $G = 9.62$ dB, at SINR $= -5.1$ dB and $\sigma = 4$ dB, and BW = 10 MHz for LTE cells, as shown in Fig. 7. However, the BW can be increased more than 10 MHz to improve the data rate as well as energy efficiency. But, should be increased P_{tx} to maintain coverage area, which means the overall energy consumption will increase, due to that the power consumed by the power amplifier is a linear function of the BS transmission power P_{tx}. Designing efficient power management is challenging because of the compromises that must be made between power savings and network performance, i.e., high data rates.

The SINR is commonly used in wireless communication as a way to measure the quality of wireless connections. Overall, when the cell radius increases, the SINR decreases because the received signal power decreases rapidly as the transmit–receive distance increases ($P_{rx}(r) = P_{tx} \times r^{-\alpha}$), which also results in an increase in path losses. The SINR requirement translates into a minimum received power P_{min} throughout the cell, when the receiver sensitivity power decreases, the coverage area of the cell increases. Thus, the UMTS technology can be detected and decoded the signals which have low SINR compare with LTE. Hence, UMTS coverage area larger than LTE.

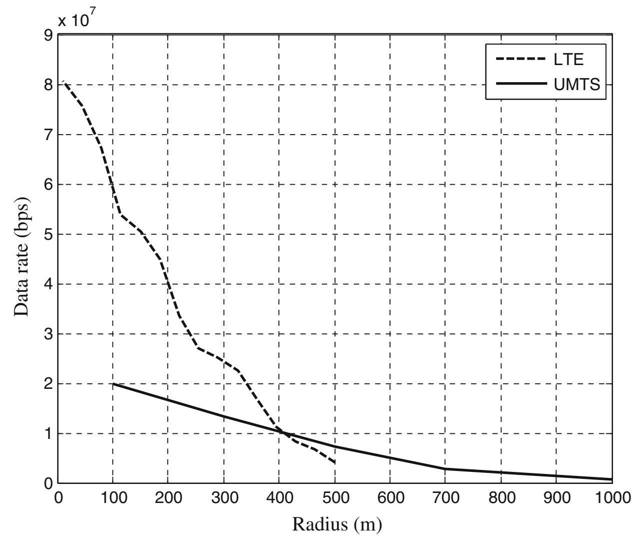


Fig. 10 Data rate versus macro-cell radii

For the downlink data transmissions, the BSs typically select the MCS based on the channel quality indicator (CQI) feedback characteristics of the UE's receiver, i.e., the SINR via a link adaptation procedure. Figure 9 shows the relationship between the radius of the cell, P_{min} and the MCS for both of the UMTS and LTE.

When the P_{min} decreases, the MCS decreases because the demodulation error rate increases as a result of the increase in both the noise and the interference that often occurs at the edge of a cell. Low-order modulation, such as QPSK, is more robust and can tolerate higher levels of interference but provides a lower transmission bit rate, whereas the high-order modulation 64-QAM offers a higher bit rate but is more susceptible to errors because of its higher sensitivity to interference, noise and channel estimation errors. Therefore, the high-order modulation 64-QAM is only useful for a sufficiently high SINR. The SINR requirement translates into a minimum received power P_{min} throughout the cell. Each radio receiver can only detect and decode signals with strengths larger than the receiver sensitivity power. It is clear that when the receiver sensitivity power decreases, the radius of the cell increases. However, it is known that increasing the radius may cause the data rate to decrease because of the low SINR, high path loss, and low MCS. However, the bit rate and data rate depend on the MCS, BW, and the number of antennas. Figure 10 highlights the data rate versus macro-cell radii for both of the UMTS and LTE.

For LTE system, the data rate is calculated in symbols per second. Furthermore, it is converted into bits per second based on the how many bits a symbol can carry, which is dependent on the MCS. Hence, for LTE with a 10 MHz BW,

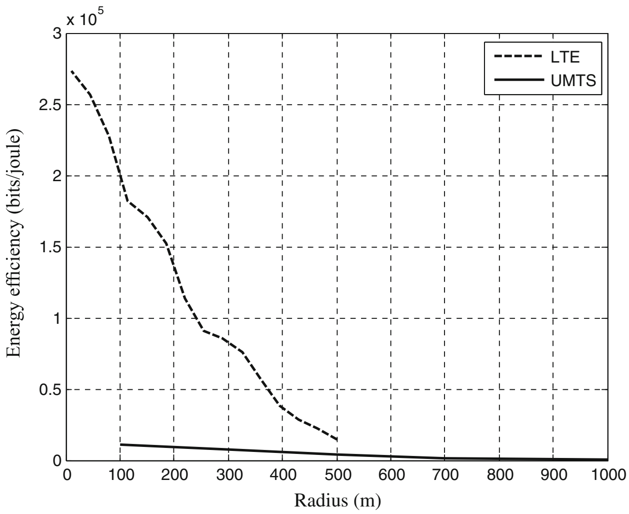


Fig. 11 Energy efficiency versus macro-cell radii

this means that there are 50 resource blocks (RBs), each RB has 12 subcarriers, each subcarrier has seven symbols for normal CP, and the time of the slot is 0.5 ms. Hence, the total number of symbols per RB is $12 \times 7 \times 2 = 168$ symbols per ms; therefore, there are 8400 symbols per ms. When 1/8 QPSK is used at the edge of the cell (two bits per symbol with coding rate 1/8), the data rate will be 2.1 Mbps for a single chain, and with 2×2 MIMO (2T, 2R), the data rate will be two times that of a single chain, i.e., 4.2 Mbps. Regarding UMTS system, assuming the physical capacity is modelled as the Shannon capacity, i.e., BW $\log_2(1 + \text{SINR})$. This study focuses on a cell radius of 1 km, which corresponds to that of a cell in an idle traffic case; the lowest modulation rate (QPSK, 1/3 rate) supports a 1 km cell radius, with the lowest data rate of 0.7 Mbps for the cell edge users.

The number of bits transmitted per joule of energy is the energy efficiency (EE). Figure 11 shows the EE performance versus the cell radii.

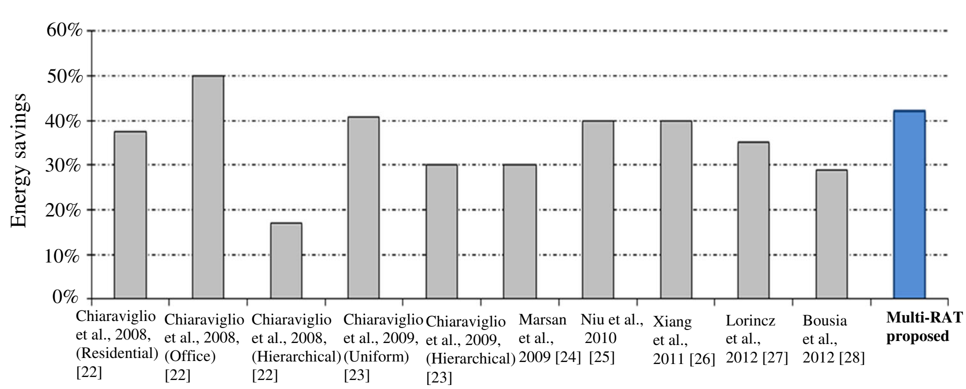
By applying the proposed switch-off scheme to the cellular network, the energy savings that can be achieved have reached 334.42 kW per day (42.26%), which translates into a 57.74% reduction. In addition, a validation of the proposed model by comparing it with other valid models in the open literature. Figure 12 summarizes the comparison of energy savings between the proposed algorithm against other models in the open literature.

7 Conclusion and remarks

This study investigated the possibility of reducing energy consumption by exploiting the coexistence of multi-RAT cellular networks—UMTS, LTE and 5G—to achieve a balance between network performance (meet the demands of high data speed rates during peak traffic hours) and energy efficiency by switching 5G-BSs off/on according to the traffic load conditions while guaranteeing service and coverage for users using LTE-BSs. A PSO technique was used to maximize the coverage area for cells during low-traffic periods to achieve energy savings at the network level under the constraints of the parameters that affect the cell coverage area: the transmission power of a BS, the total antenna gain, the bandwidth, the signal-to-interference plus noise ratio, and shadow fading. The simulation results show that when the cell coverage area increases, the shadowing increases and the SINR decreases, translating into a minimum received power, which may impact the detected and decoded signals. However, the transmitted power and antenna gain maintain high coverage at the edge of the cell. Designing efficient power management is challenging because of the compromises that must be made between power savings and network performance, i.e., high data rates. This study demonstrated by applying the proposed multi-RAT BSs switch-off scheme to the cellular network, the energy savings that can be achieved up to 42.3%.

For future work, a massive MIMO in 5G technology has degrees of freedom in excess. These available degrees of freedom can be exploited to make antenna switching off/on during a high traffic load conditions; which increases the energy saving in the cellular network. However, the antenna switching off/on should follow certain design prin-

Fig. 12 Energy saving of the proposed approach versus the other models in the literature. [22–28]



ciples. Practical factors, such as geographical location of BSs (urban, suburban), the coverage area of BSs, traffic load, propagation environment (signal-to-noise ratio, path loss or fading), antenna tilt angles, height, transmit power and energy consumption are the realistic elements that should be taken into account for implementation and evaluation.

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Compliance with ethical standards

Conflicts of interest The authors declare that they have no competing interests.

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