entropy

MDPI

Article

Modeling and Performance Evaluation of a Context Information-Based Optimized Handover Scheme in 5G Networks

Dong Yeong Seo [1] and Yun Won Chung [2,*]

[1] Department of Information and Telecommunication Engineering, Graduate School, Soongsil University, 369 Sangdo-ro, Dongjak-gu, Seoul 06978, Korea; seody@ssu.ac.kr

[2] School of Electronic Engineering, Soongsil University, 369 Sangdo-ro, Dongjak-gu, Seoul 06978, Korea

* Correspondence: ywchung@ssu.ac.kr; Tel.: +82-2-820-0908

Received: 10 May 2017; Accepted: 22 June 2017; Published: 3 July 2017

Abstract: Recently, green networks are considered as one of the hottest topics in Information and Communication Technology (ICT), especially in mobile communication networks. In a green network, energy saving of network nodes such as base stations (BSs), switches, and servers should be achieved efficiently. In this paper, we consider a heterogeneous network architecture in 5G networks with separated data and control planes, where basically a macro cell manages control signals and a small cell manages data traffic. Then, we propose an optimized handover scheme based on context information such as reference signal received power, speed of user equipment (UE), traffic load, call admission control level, and data type. In this paper, the main objective of the proposed optimal handover is either to reduce the number of handovers or the total energy consumption of BSs. To this end, we develop optimization problems with either the minimization of the number of total handovers or the minimization of energy consumption of BSs as the objective function of the optimization problem. The solution of the optimization problem is obtained by particle swarm optimization, since the developed optimization problem is an NP hard problem. Performance analysis results via simulation based on various probability distributions of the characteristics of UE and BS show that the proposed optimized handover based on context information performs better than the previous call admission control based handover scheme, from the perspective of the number of handovers and total energy consumption. We also show that the proposed handover scheme can efficiently reduce either the number of handovers or the total energy consumption by applying either handover minimization or energy minimization depending on the objective of the application.

Keywords: context information; particle swarm optimization; handover; energy consumption

1. Introduction

Recently, green networks are considered as one of the hottest topics in Information and Communication Technology (ICT), especially in mobile communication networks [1–3]. In a green network, energy saving of network nodes such as base stations (BSs), switches, and servers should be achieved efficiently [3]. In particular, BS energy savings should be achieved at a significant level since BSs are responsible for a major part of the power consumption. To reduce the power consumption of BSs, the basic functional command is to turn BSs off when traffic load is very low [3]. Also, the traffic load of the turned off BSs should be managed by neighboring BSs. Energy flows and entropy in communication networks can be evaluated. Examples of exergy-based lifecycle analysis of ICT equipment such as Node B and smartphone of fourth generation (4G) universal mobile telecommunication systems (UMTS) and exergy-based lifecycle analysis of radio access network are presented [4].

In [5], a night zone is defined, where the traffic load of a BS is low and therefore the BS can be turned off. The quality of service (QoS) of user equipment (UE) is guaranteed by controlling the transmission power of a BS in a night zone. In [6], the number of optimal BSs which can be turned off in a night zone in various macro cell layout scenarios using traffic patterns was derived but this optimization does not react to a dynamically varying traffic load environment. In a green base station network [7], BSs are clustered based on the distance between BSs, and BSs are turned on or off based on the traffic load in each cluster. During a peak hour, all the BSs are activated first and then BSs are turned off gradually based on the status of the traffic load. In [8], the distance between a BS and a UE is measured and BSs are turned off based on the descending order of the average distance from UEs. In [9], the authors use the distance between a BS and UE in order to associate UEs with a BS and BSs with load traffic load, especially during night, are turned off to reduce the power consumption of BSs without sacrificing the quality of service. In [10], to solve the coverage hole problem due to the turned off BSs, the number of activated BSs and the cell size are determined, while minimizing the energy consumption of BSs. In [11], the authors propose switching-on/off energy saving algorithm by turning off a BS one by one with the ascending order of network-impact. Then, they propose three heuristics using network-impact and show that the proposed heuristics significantly achieve energy saving.

In cell zooming [12], based on the traffic load of BSs, the cell coverage is adjusted accordingly by controlling the transmission power of BSs. If a BS has low traffic load, the cell coverage is reduced, and neighboring BSs extend the cell coverage. In [13], efficient energy saving of BSs are proposed, of which a certain ratio of BSs is turned off in a time zone with a low traffic load and the cell size of the active BSs are extended by increasing the transmission power of active BSs.

In a heterogeneous network architecture, where macro cell BSs and small cell BSs overlap, the energy of BSs is saved by turning off small cell BSs when they are not in use [14]. In a heterogeneous network, a macro cell BS controls the activation and deactivation of small cell BSs based on the feedback on the traffic load of UEs and position information of UEs from small cell BSs. However, this results in signaling overhead between a macro cell BS and small cell BSs [15]. In distributed activation/deactivation schemes [16], each small cell BS decides whether it should be activated or deactivated. If there is no UE within the coverage of a small cell BS, it is turned off. Then, it periodically activates to detect the signal between a macro cell BS and UEs, and it is turned on if there is any UE which should be served by the small cell BS. In device-assisted-networking for cellular greening (DANCE) scheme, a macro cell BS manages the control signal of UEs and a small cell controller activates or deactivates the small cell BSs when the traffic load varies to optimize the number of activated/deactivated small cell BSs [17]. In [18], the authors propose a joint BS on/off switching and user association algorithm in order to maximize the energy efficiency, based on the time- and space-dependent traffic load in massive MIMO heterogeneous networks. In [19], the authors change the on/off states of small cell BSs dynamically based on UE distribution. In uniform UE distribution, small cell BSs are turned off with the ascending order of the distance with the macro cell BS. In non-uniform UE distribution, a joint location and user density based scheme is proposed and near-optimum solution is obtained. In [20], the authors discuss the technical challenges of BS on/off switching in 5G systems, summarize the state of the art on BS on/off switching, and present challenges and open problems.

In [21], the authors introduce four different sleep modes to small cell BSs depending on the consumed energy levels. Then, they formulate an optimization problem for energy efficiency maximization based on either a random sleeping or a strategic sleeping policy for small cell BSs. In [22], the authors analyze the impact of the sleeping of BSs on energy efficiency and user-perceived delay based on three wake-up schemes such as single sleep, multiple sleep, and N-limited schemes. Then, they formulate an optimization problem for delay-constrained energy-optimal BS sleeping policies and analyze the tradeoff between energy saving and mean delay. In [23], the authors analyze the tradeoff between energy consumption and grade of service degradation when the different sleeping patterns of BSs are considered.

In [24–28], energy efficiency of BSs shared by multiple operators is analyzed. In [24], in order to reduce the energy consumption and operational cost in cellular networks, network sharing is considered, in addition to the switching off of BSs. The authors introduce the concept of intra-cell roaming, where UEs of a specific mobile network operator are roamed to another BSs operated by other mobile network operators, and the operator turns off its BSs. Then, they propose a distributed game theoretic BS switching off scheme and analyze the energy saving and cost saving. In [25], the authors propose a cooperative BS switching off scheme, where macro cell BSs and small cell BSs are turned off when the traffic load is low and UEs are served by BSs operated by other mobile network operators in order to guarantee the quality of service. In [26], the authors propose game-theoretic approaches, i.e., pricing decision game and user association game, based on the relationship between roaming price and user association in multi-mobile network operator environment. Then, they reveal that significant energy saving is achieved in the proposed approaches. In [27], the authors propose an auction-based switching-off scheme, by using the fact that network is underutilized if traffic load is low and thus third party small cells can be used to offload its traffic and BSs can be turned off to save power. The proposed scheme consists of a bidding strategy and an auction scheme which maximize the profit and minimizes energy consumption. In [28], the authors propose a game-theoretic infrastructure sharing scheme, where mobile network operators estimate the switching-off probabilities that can reduce their cost and finally equilibrium state is achieved that minimizes the cost of each operator. In [28], an analytical model is developed using voice and data traffic model.

Regarding the works on network architecture for a green network, third generation partnership project (3GPP) proposed the concept of separation of data plane and control plane for 5G networks [29]. In the separated architecture, a macro cell covers a large area and manages the control signal, and a small cell covers a small area and manages data, as shown in Figure 1. In this architecture, a small cell BS can be turned off, if there is little UE with data service in the coverage area. The power of a BS can be saved, while connectivity with network can be provided using a macro cell. Also, UE can be connected with a macro cell always and therefore, handover can be managed seamlessly and power of a BS can be saved, since signaling overhead due to handover can be reduced.

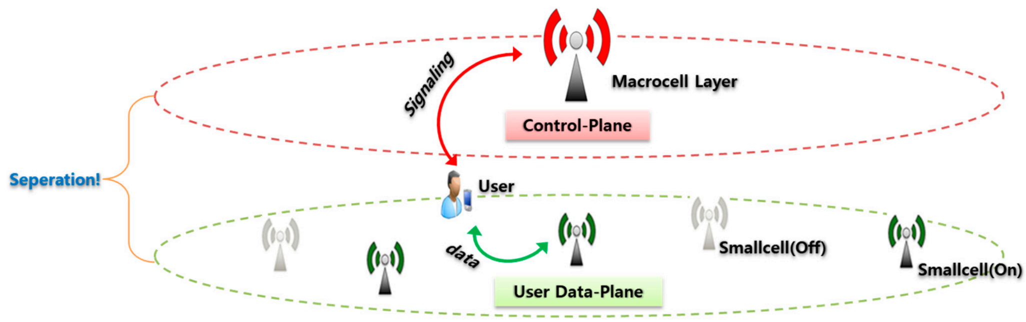


Figure 1. Separation of data plane and control plane for 5G networks.

Of works regarding separate network architectures, the work in [30,31] analyzed the efficiency of accommodating UEs for varying the number of small cells and the distance between a UE and a BS. The work in [32] defines the threshold ratio of a small cell BS in sleep state. Then, if the ratio of small cell BSs in sleep state is less than the threshold ratio, small cell BSs with low traffic load are turned off, and traffic load covered by small cell BSs are handed over to neighboring small cell BSs. Otherwise, BSs with high traffic load are turned off, and the traffic load managed by small cell BSs are distributed to neighboring small cell BSs. Using these algorithms, power consumption of BSs can be minimized. In [33], the authors propose dynamic traffic BS switching on/off scheme, in separated network architecture with coverage BS and traffic BSs, where random sleeping is considered. In [34], two sleeping schemes, i.e., random and repulsive schemes, are proposed in a separated network, where vertical offloading between a macro cell and a small cell is assumed. In random scheme, a small cell BS is turned off with probability p. In repulsive scheme, small cell BSs which are located within a distance R from a macro cell BS are turned off. Then, they derive maximum p and R, while satisfying the outage constraints.

In a call admission control (CAC)-based handover scheme [35], the authors classified the types of handovers in heterogeneous networks. Also, a call is admitted based on the signal-to-noise-plus-interference ratio (SINR), signal level, speed of UE, so unnecessary handover signaling can be reduced. As an extension of the work in [35], the authors in [36] proposed an optimized CAC-based handover based on context information such as reference signal received power (RSRP), speed of UE, traffic load of target cell, and handover admission control. In the optimized CAC-based handover [36], traffic load is directed to some BSs with high traffic load. Then, BSs with low traffic load are turned off so significant BS power consumption can be saved. Figure 2 shows that a UE hands over to a BS with better RSRP in a traditional handover approach, but in CAC-based handover, a UE hands over based on context information, and thus, a high speed UE hands over to a macro cell BS and a low speed UE hands over to a small cell BS. In [37], a prediction-based association control scheme is proposed in order to reduce unnecessary handover in a femtocell environment, without degrading throughput. In [38], reduced early handover is proposed in order to save the energy of BSs, while maintaining acceptable radio link failure, where early handover is carried out based on prediction using RSRP from BSs.

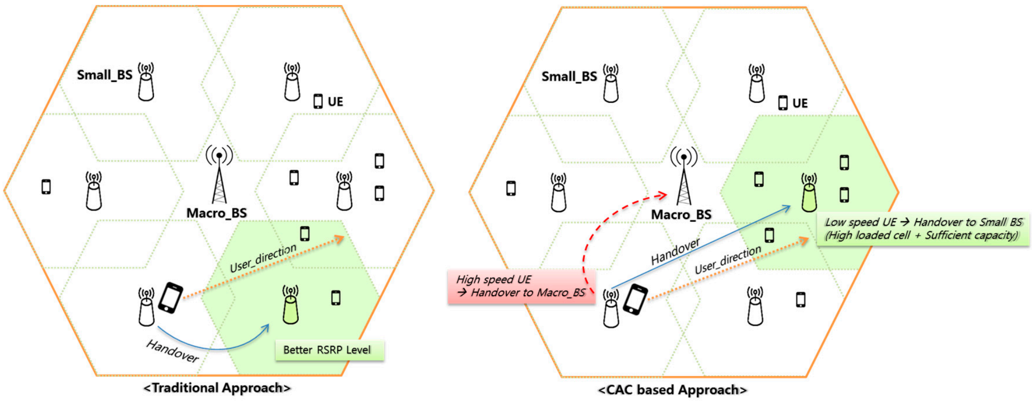


Figure 2. Handovers in a traditional approach and a CAC-based approach.

In [39], the authors used the concept of information theory for the efficient mobility and resource management in future cellular networks, which are two main problems in cellular networks. Since overhead in the mobility and resource management are basically generated from the random behavior of UEs' movement and resulting uncertainty of UEs' position, the authors developed an information-theoretic approach for utilizing this uncertainty using the entropy or information content of UEs' movement. The authors revealed that the proposed information-theoretic mobility management scheme can reduce overhead by approximately 80 percent. In [40], the authors used the concept of entropy in the network selection in heterogeneous network architectures. The authors used UE-side requirements and network-side requirements for an efficient network selection. To this end, the authors defined weights of multiple criteria of UE-side and network-side requirements using an analytic hierarchy process. Entropy was also used to define weights of network-side requirements.

Although the authors in the work in [35,36] developed an efficient call admission control scheme, they did not consider separate control and data planes. Also, context information on data type of a service, i.e., low rate data traffic or high rate data traffic, was not considered for handover decisions. To extend the previous works on CAC-based handover [35,36], we consider a new heterogeneous network architecture in 5G networks with separate data and control planes, where a macro cell BS manages control signals and a small cell BS manages data. In addition to previously used context information such as RSRP, speed of UE, traffic load of target cell, and admission control level, we newly consider the data type of a service, i.e., low rate data traffic and high rate data traffic. Then, we propose an optimized handover scheme considering the mentioned context information. An optimization problem is formulated and the solution is obtained by particle swarm optimization, since the optimization problem is non-deterministic polynomial-time hard (NP hard). The basic idea of the proposed optimized handover scheme is similar to the work presented in our preliminary work [41] but the proposed work is significantly extended from the previous work according to the following aspects:

- The proposed optimized handover scheme is extended and more elaborated from our previous work so a UE with low speed and low rate data traffic can be handed over to a small cell BS, depending on the traffic load condition of neighboring small cell BSs.
- A thorough optimization problem for the proposed handover scheme is formulated, from the aspect of the minimization of the number of handovers and energy consumption of BSs, for the performance analysis based on context information such as RSRP, speed of UE, traffic load, call admission control level, and data type.
- The particle swarm optimization is applied to solve the formulated optimization problem heuristically.
- Extensive numerical examples are obtained through simulation based on the assumption of specific probability distributions of various random variables defined in this paper, and the performance of the proposed scheme is evaluated in detail.

The remainder of this paper is organized as follows: Section 2 proposes an optimized handover scheme based on context information and formulates an optimization problem. In Section 3, numerical examples are presented. Finally, Section 4 concludes this work.

2. An Optimized Handover Based on Context Information

2.1. System Model

In this paper, we assume heterogeneous network architecture with a macro cell with overlaid small cells overlapped with each other, as shown in Figure 3, where small cells are concentrated at a few hot spot areas. We note that only a single macro cell is assumed in this paper for simplicity, similar to the work in [33], and the multi-macro cell environment will be considered in our future work. The mobility of a UE follows a random movement model, where locality is assumed for UEs in the small cells at hot spot areas. The speed of a UE follows a uniform distribution. Data traffic generated at a UE is determined as either low rate data traffic or high rate data traffic based on a predefined value of the ratio of high rate data traffic.

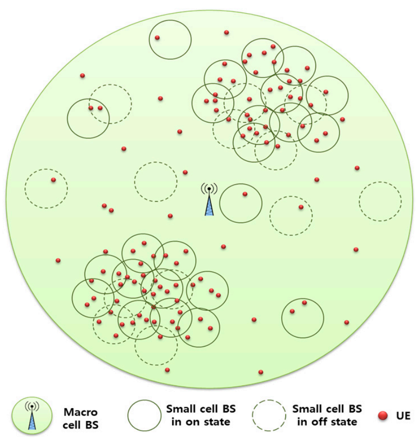


Figure 3. Network Configuration.

The notations defined in this paper are summarized in Table 1.

Table 1. Notations.

Value	Description
B_{Mm}	A macro cell BS m
B_{Ss}	A small cell BS s
u_k	A user equipment k
w_{Mm}	State of a macro cell
w_{Ss}	State of small cell
$a_{Mm,k}$	Service state of u_k in a macro cell
$a_{Ss,k}$	Service state of u_k in a small cell
d_k	Existence of data service requested by u_k
r_k	Required data type by u_k
v_k	Speed of u_k
$D\_Cell_{load\_B_{target\_BS,\ k}}$	Traffic load of a target cell
$B_{target\_m,k}$	A target macro cell BS m of a UE k
$B_{target\_s,k}$	A target small cell BS s of a UEk
$B_{serv\_m,k}$	A serving macro cell BS m of a UE k
$B_{serv\_s,k}$	A serving small cell BS s of a UE k
B_{avail_Mm}	A set of available macro cell BS m
B_{avail_Ss}	A set of available small cell BS s
P^{max}_{Macro}	Maximum power consumption in macro cell with on state
P^{max}_{Small}	Maximum power consumption in small cell with on state
P^{static}_{Macro}	Static power consumption in macro cell with on state
P^{static}_{small}	Static power consumption in small cell with on state
P_{Macro_linear}	Slope of power consumption in macro cell to transmit UE data
P_{Small_linear}	Slope of power consumption in small cell to transmit UE data
P_{Macro_total}	Total power consumption of a macro cell
P_{Small_total}	Total power consumption of a small cell
$P(Ss)_{small}$	Total power consumption of s-th small cells
P_{total}	Total power consumption of BSs
u_{Mm_served}	A set of served UEs by BS_{Mm}
u_{Ss_served}	A set of served UEs by BS_{Ss}
$RSRP_{B_{serv\_m,k}}$	Reference signal received power of $BS_{serv\_m,\ k}$
$RSRP_{B_{serv\_s,k}}$	Reference signal received power of $BS_{serv\_s,\ k}$
$C_{B_{target\_BS,k}}$	Condition of Admission control level
C	Total capacity of a cell
C^{max}_{Macro}	Total capacity of a macro cell
C^{max}_{small}	Total capcity of a small cell
C'	Actual capacity needed for an active user
C_{req}	Requested capacity by a handover call
C_{req_high}	Requested capcity by a handover call having high rate data service
C_{req_low}	Requested capcity by a handover call having low rate data service
$No\_UE_{high\_rate}$	Number of users requiring high rate data service
$No\_UE_{low\_rate}$	Number of users requiring low rate data service
TH_{HO}	Percentage of cell capacity reserved for handover calls
L_threshold	Threshold of supposing cell has low traffic loads
V_threshold	Threshold of user speed having high and low speed
HO_{case}	The case of comming handover
HO_{total}	Total number of handovers

2.2. An Optimized Handover Scheme

In this paper, a UE periodically checks the RSRP of neighboring BSs and it searches target cell list if the RSRP of currently associated BS is smaller than a predefined threshold, as defined in 3GPP [35]. Then, it makes target cell list. In this paper, the speed of a UE is classified as either low or high, and the data rate of a service is classified as either low rate data traffic or high rate data traffic. Then, the speed and data rate of a UE are used to decide a target cell list. Similar to the work in [36], the condition of Equation (1) for call admission control is checked against cells in target cell list, where C', C_{req}, TH_{HO}, and C represent required capacity by active UEs, capacity required by a handover call, the ratio of reserved cell capacity for a handover call, and the total capacity, respectively. If the condition of Equation (1) is not satisfied at a cell, the cell is removed from the target cell list:

$$C' + C_{req} \leq TH_{HO} \times C \tag{1}$$

Figure 4 shows the flowchart of the proposed handover. A UE checks the RSRP of a serving cell and compares it with a threshold value. Then, if a handover is needed, the UE finds neighbor BSs satisfying RSRP condition.

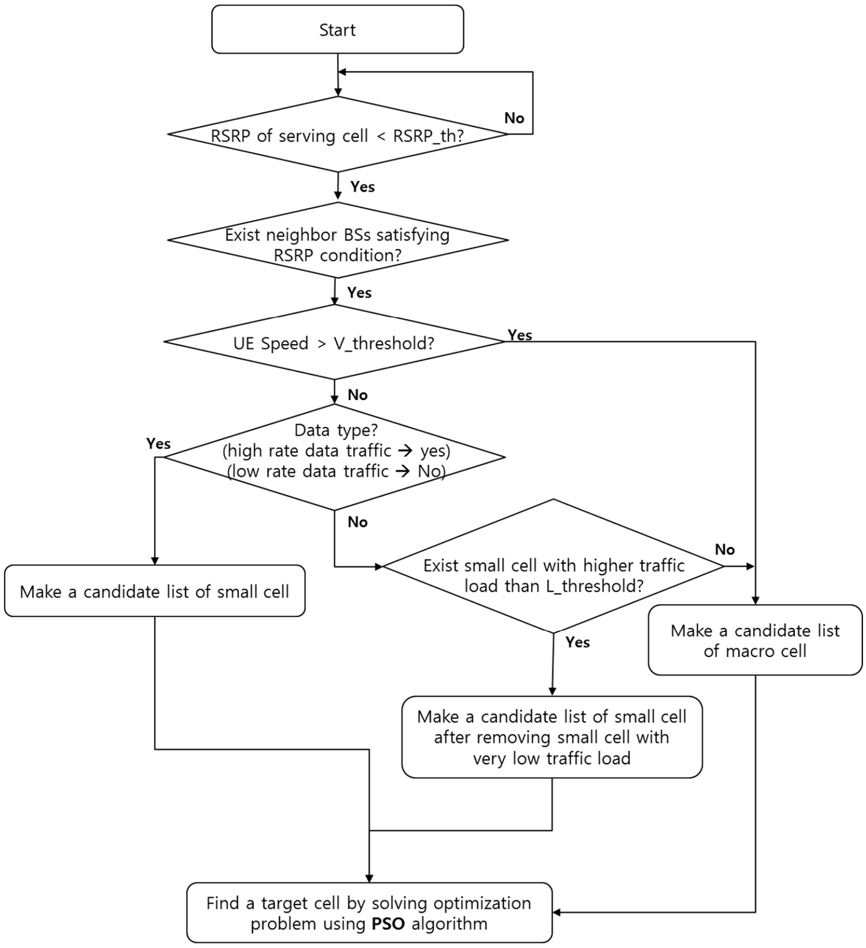


Figure 4. Flowchart of the proposed handover.

For high speed UE, the service of a UE is handed over to a macro cell to reduce the number of handovers, since frequent handovers between small cells and between a small cell and a macro cell, due to high speed UEs, degrade the quality of experience of UEs. Therefore, the UE makes a candidate list of macro cell and finds a target macro cell by solving optimization problem using PSO algorithm. For low speed UE, different criterion is applied for selecting a target cell depending on the type of data traffic. If a UE has high rate data traffic, it is handed over to a small cell BS, if there is any available small cell BS in order to offload more traffic from a macro cell BS. Therefore, the UE makes a candidate list of small cell and finds a target small cell by solving optimization problem using PSO algorithm. If a UE has low rate data traffic, it can be handed over to either a small cell BS or a macro cell BS. If there is any neighboring small cell BS which has higher traffic load than a threshold, it is handed over to a small cell BS. Therefore, the UE makes a candidate list of small cell after removing small cell with very low traffic load, since it is better to turn off the small cell with very low traffic load to save energy, by removing it from a candidate list of small cell. Then, it finds a target small cell by solving optimization problem using PSO algorithm. If there is no neighboring small cell BS which has higher traffic load than a threshold, it is handed over to a macro cell BS. Therefore, the UE makes a candidate list of macro cell and finds a target macro cell by solving optimization problem using PSO algorithm.

Although the idea of using traffic type and speed to associate a UE with a macro cell BS or a small cell BS in separated network architecture is similarly presented in [34], where only the UE with low speed and high rate data traffic is associated with a small cell BS and other UEs are associated with a macro cell BS, our proposed idea is different from the work in [34], since a UE with low speed and low rate data traffic can be handed over to a small cell BS, depending on the traffic load condition of neighboring small cell BSs. Also, although it is mentioned that the speed of UE is considered to select a target cell for association in [34], the mobility of UE is not considered actually at the analysis of the proposed sleeping schemes. On the other hand, our proposed scheme considers both data traffic type and mobility together to make a handover decision.

Figures 5 and 6 show examples of a CAC-based handover scheme and the proposed handover scheme, respectively. In Figure 5, a data type, i.e., low rate data traffic or high rate data traffic, is not considered for a handover decision. It is assumed that cars, which are denoted as UE_C, move at high speed and connect to a macro cell BS. Pedestrians that are denoted as UE, move at a low speed and connect to small cell BSs. Low speed UEs 1, 2, 5, 6, and 7 move into new small cells along the directions of arrows and handed over to new small cell BSs. A high-speed UE moves from small cell 1 to small cell 2, but it is not handed over to small cell BS2, and therefore small cell BS2 can be turned off to save power.

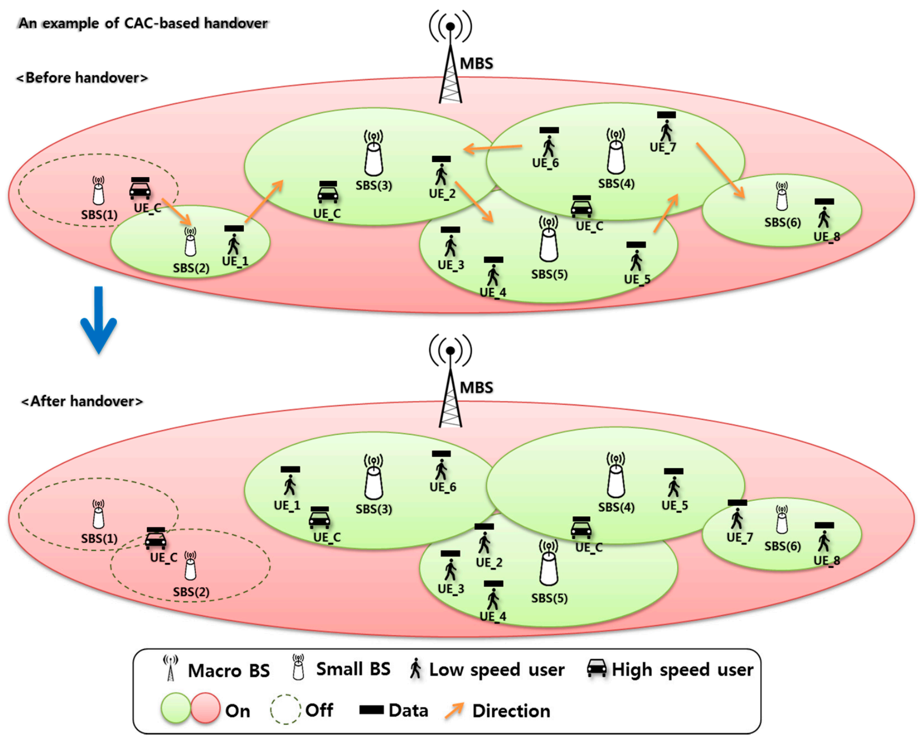


Figure 5. An example of CAC-based handover.

In Figure 6, handover is carried out based on the data type and speed of UE. Thus small cell BS 6 is turned off before handover since UE 8 has low rate data traffic and low speed and it can be connected to a macro cell BS if SBS(6) has very low traffic load. Low speed UEs 1, 2, 5, 6, and 7 move into new small cells along the direction of arrows and handed over to new small cell BSs. Small cell BS 4 can be turned off since high speed UE 6 and UE 7 move out of the small cell and UE 5 moving into the small cell has low rate data traffic and low speed and it is handed over to a macro cell BS since the traffic load of SBS(4) is very low. A high speed UE moves from small cell 1 to small cell 2 but it is not handed over to small cell BS2 but to a macro cell BS, and thus small cell BS2 can be turned off to save power. As shown in Figures 5 and 6, the proposed handover scheme can turn off more BSs.

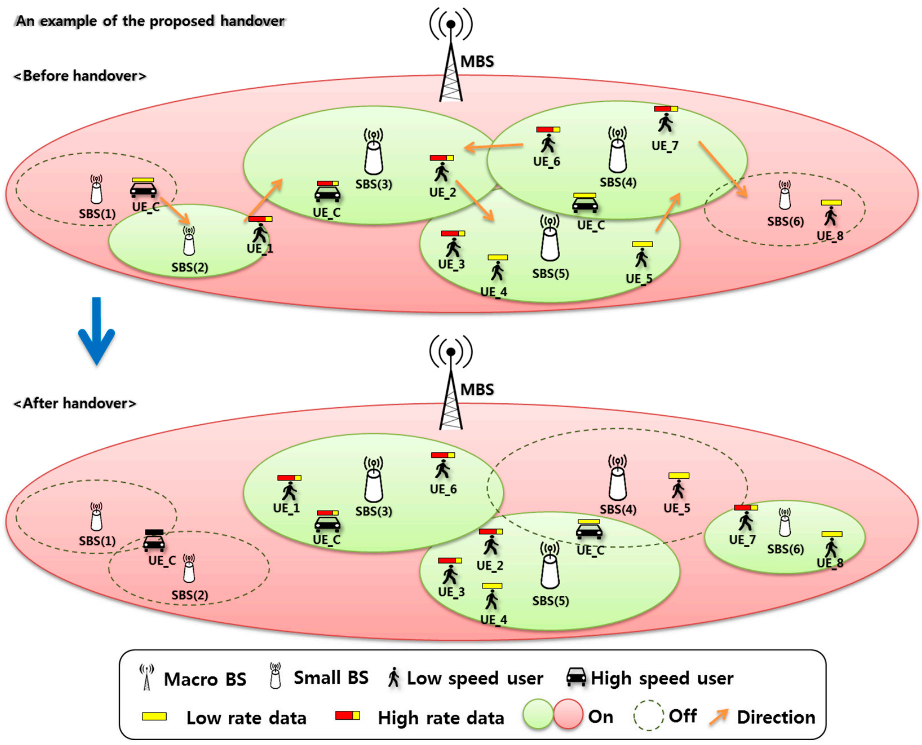


Figure 6. An example of proposed handover.

In this paper, the main objective of the proposed optimal handover is either to reduce the number of handovers or the total energy consumption of BSs. To this end, we develop optimization problems with either the minimization of the number of handovers or the minimization of energy consumption of BSs as the objective function of the optimization problem.

To check service availability of a BS, the state of a macro cell and a small cell is classified as on and off, as in Equations (2) and (3):

$$w_{Mm} = \begin{cases} 1, & \text{if } B_{Mm} \text{ is ON state} \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

$$w_{Ss} = \begin{cases} 1, & \text{if } B_{Ss} \text{ is ON state} \\ 0, & \text{otherwise} \end{cases} \tag{3}$$

Also, the service state of UE k in a macro cell and a small cell are defined as in Equations (4) and (5):

$$a_{Mm,k} = \begin{cases} 1, & \text{if } u_k \text{ is served by } B_{Mm} \\ 0, & \text{otherwise} \end{cases} \tag{4}$$

$$a_{Ss,k} = \begin{cases} 1, & \text{if } u_k \text{ is served by } B_{Ss} \\ 0, & \text{otherwise} \end{cases} \tag{5}$$

The existence of data service request by UE k, the data type of UE k, and the speed of UE k are defined as in Equations (6)–(8):

$$d_k = \begin{cases} 1, & \text{if } u_k \text{ requires data services} \\ 0, & \text{otherwise} \end{cases} \tag{6}$$

$$r_k = \begin{cases} 1, & \text{if } u_k \text{ requires high rate data services} \\ 0, & \text{if } u_k \text{ requires low rate data services} \end{cases} \quad (7)$$

$$v_k = \begin{cases} 1, & \text{if } u_k \text{ has high speed velocity } > \text{ V\_threshold} \\ 0, & \text{if } u_k \text{ has low speed velocity } \leq \text{ V\_threshold} \end{cases} \quad (8)$$

The traffic load of a macro cell and a small cell are defined as in Equation (9):

$$D\_Cell_{load\_B_{target\_BS,\ k}} = \begin{cases} 1, & \text{if a trrafic of } B_{target\_BS,k} \text{ is the highest level} \\ 0, & \text{otherwise} \end{cases} \quad (9)$$

In order to consider the RSRP of BSs, A2 and A3 events [35,36] are defined as in Equations (10) and (11):

$$A2_{B_{serv\_BS,\ k}} = \begin{cases} 0, & \text{if A2 event condition is satisfied} \\ 1, & \text{otherwise} \end{cases} \quad (10)$$

$$A3_{B_{target\_BS,\ k}} = \begin{cases} 1, & \text{if A3 event condition is satisfied} \\ 0, & \text{otherwise} \end{cases} \quad (11)$$

Finally, admission control level is defined as in Equation (12):

$$C_{B_{target\_BS,\ k}} = \begin{cases} 1, & \text{if } C\prime + C_{req} \leq TH_{HO} \times C \\ 0, & \text{otherwise} \end{cases} \quad (12)$$

Considering all the previous equations, the possible handover is defined as in Equation (13):

$$HO_{case} = \sum_{B_{avail\_BS}=1}^{Num\_BSs \text{ in on state}} \sum_{k=1}^{u_{BS\_served}} d_k \times a_{BS,k} \times (A2_{B_{serv\_BS,\ k}} \times A3_{B_{target\_BS,\ k}}) \times v_k \times D\_Cell_{load\_B_{target\_BS,\ k}} \times r_k \times C_{B_{target\_BS,\ k}} \quad (13)$$

The possible handover cases are summarized in Table 2.

Table 2. Possible handover cases.

Cases	Description
case 1	A UE serviced by a macro cell currently handovers to another macro cell
case 2	A UE serviced by a macro cell currently handovers to a small cell
case 3	A UE serviced by a small cell currently handovers to a macro cell
case 4	A UE service by a small cell currently handovers to another small cell

The total number of handovers is defined as in Equation (14):

$$HO_{total} = HO_{case1} + HO_{case2} + HO_{case3} + HO_{case4} \quad (14)$$

Based on the number of handovers, we obtain the total energy consumption of a macro cell BS and a small cell BS as in Equations (15) and (16), of which the $No\_UE_{low\_rate}$ and $No\_UE_{high\_rate}$ represent the number of served UE with low rate data traffic and UE with high rate data traffic, respectively:

$$P_{Macro\_total} = P_{Macro\_static} + P_{Macro\_linear} \times \left\{ \frac{(C_{req\_high} \times No\_UE_{high\_rate}) + (C_{req\_low} \times No\_UE_{low\_rate})}{C_{Macro}^{max}} \right\} \quad (15)$$

$$P_{Small\_total} = P_{Small\_static} + P_{Small\_linear} \times \left\{ \frac{(C_{req\_high} \times No\_UE_{high\_rate}) + (C_{req\_low} \times No\_UE_{low\_rate})}{C_{small}^{max}} \right\} \quad (16)$$

Then, the total energy consumption of BSs in the considered network is obtained using Equation (17):

$$P_{Total} = P_{Macro\_total} + \sum_{k=1}^{Num\_SBSs\ in\ on\ state} P_{Small\_total,\ k} \tag{17}$$

Finally the optimization problem of the proposed scheme to minimize the number of handovers is formulated as in Equation (18):

$$\begin{array}{ll} \min & HO_{total} \\ \text{s.t.} & a_{m,k} \le w_{Mm} \\ & a_{n,k} \le w_{Ss} \\ & r_k \le d_k \\ & \sum_{n=1}^{Num\_SBSs} a_{n,k} \le 1 \\ & w_{Mm},\ w_{Ss} \le 1 \\ & 1 \le k \le Num\_UEs, \quad 1 \le n \le Num\_SBSs \end{array} \tag{18}$$

The optimization problem of the proposed scheme to minimize the energy consumption of BSs is formulated as in Equations (19)–(22). Considering all the previous equations, the possible power consumption of a small cell is defined as in Equation (19):

$$\begin{aligned} P(Ss)_{small} = w_{Ss} \times \Big(& P_{small}^{static} + P_{Small\_linear} \\ & \times \sum_{k=1}^{Num\_UEs} \Big(d_k \times a_{Ss,k} \times (1 - A2_{B_{serv\_BS,\ k}}) \times A3_{B_{target\_BS,\ k}} \times (1 - v_k) \\ & \times C_{B_{target\_BS,\ k}} \times D\_Cell_{load\_BS_{target\_BS,\ k}} \\ & \times \frac{(r_k \times C_{req\_high} + (1 - r_k) \times C_{req\_low})}{C_{small}^{max}} \Big) \Big) \end{aligned} \tag{19}$$

Also, possible power consumption of a macro cell is defined as in Equation (20):

$$\begin{aligned} P_{Macro\_total} = w_{Mm} & \\ \times \Big(& P_{Macro}^{static} + P_{Macro\_linear} \\ \times & \sum_{k=1}^{Num\_UEs} \Big(d_k \times a_{Mm,k} \times \Big(1 - A2_{B_{serv\_BS,\ k}}\Big) \times A3_{B_{target\_BS,\ k}} \times v_k \times C_{B_{target\_BS,\ k}} \\ \times & D\_Cell_{load\_BS_{target\_BS,\ k}} \times \frac{(r_k \times C_{req\_high} + (1 - r_k) \times C_{req\_low})}{C_{Macro}^{max}} \Big) \Big) \end{aligned} \tag{20}$$

The total energy consumption is defined as in Equation (21):

$$P_{Total} = P_{Macro\_total} + \sum_{Ss=1}^{Num\_SBSs} P(Ss)_{Small\_total} \tag{21}$$

Finally the energy optimization problem of the proposed scheme is formulated as in Equation (22):

$$\begin{array}{ll} \min & P_{total} \\ \text{s.t.} & P(n)_{small} \le nP_{Small}^{max} \\ & P_{macro} \le P_{Macro}^{max} \\ & a_{Mm,k} \le w_{Mm} \\ & a_{Ss,k} \le w_{Ss} \\ & r_k \le d_k \\ & \sum_{n=1}^{Num\_SBSs} a_{Ss,k} \le 1 \\ & w_{Mm}, w_{Ss} \le 1 \\ & 1 \le k \le Num\_UEs, \quad 1 \le n \le Num\_SBSs \end{array} \tag{22}$$

Since the optimization problem formulated is a NP hard problem, we obtain the solution of the optimization problem using particle swarm optimization [42,43], which is a widely used bio-inspired algorithm, like genome-based approach [44]. The particle swarm optimization is easy to implement and calculated easily within a short time. It has been applied to many network issues such as resource allocation problem [45], routing algorithms [46], and the concept of information theory and entropy were used in the development of particle swarm optimization. In this paper, the discrete particle swarm optimization (DPSO) [43] is applied to obtain the solution to the proposed optimization problem.

Figure 7 shows the flowchart of the particle swarm optimization of the proposed handover scheme, which is based on [47]. To obtain an initial solution, the values of number of particles, learning factors, and dimension of particles were initialized. Also, the number of iterations is initialized as 500. Then, conditions of the proposed optimization problems were initialized as particles by random positioning and the initial value of the particle was initialized as 0. Then, initial fitness was evaluated for each particle position. After that, local best fitness pbest and position were obtained, and global fitness gbest and position were obtained.

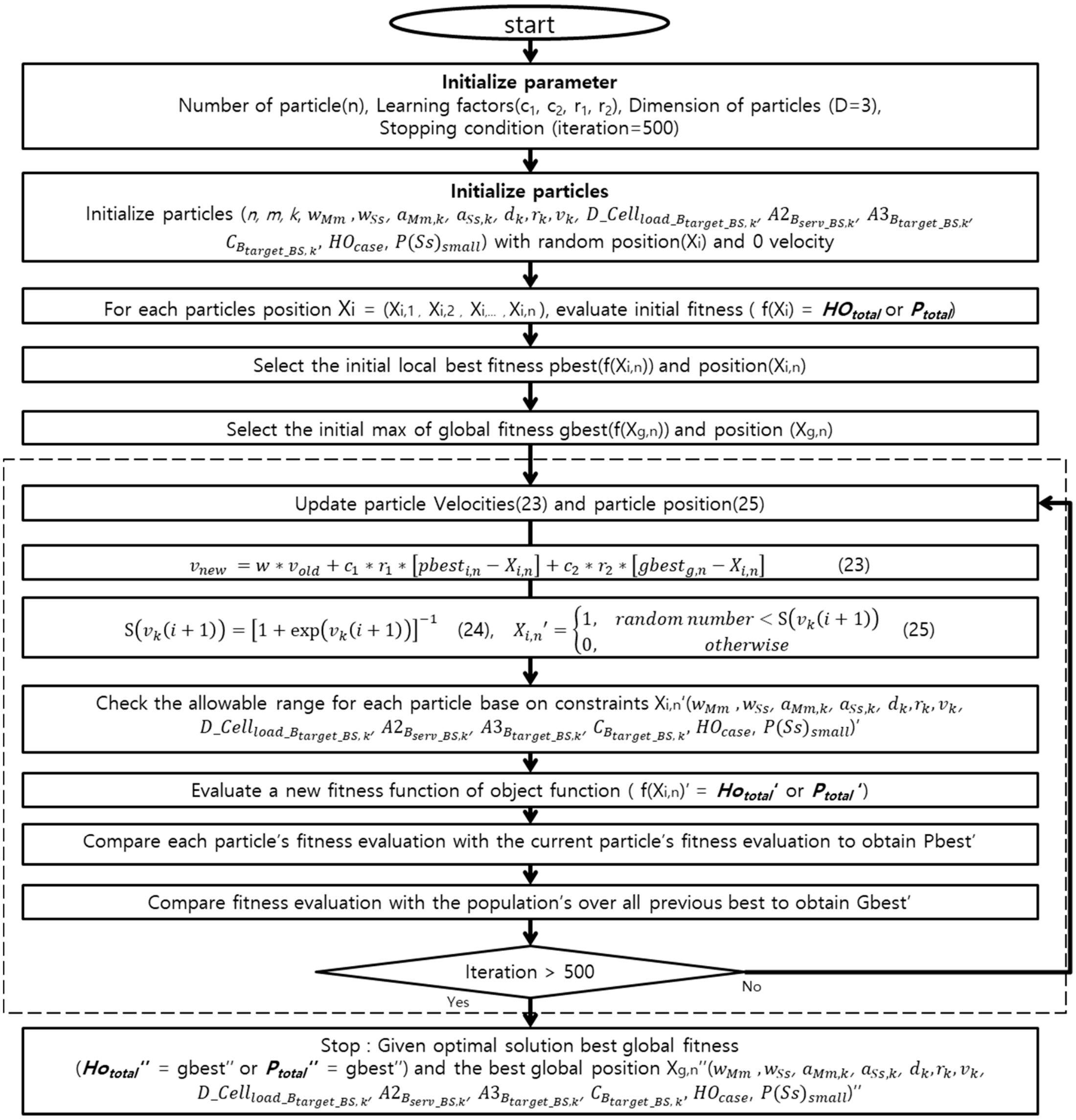


Figure 7. Flowchart of the particle swarm optimization of the proposed handover scheme.

The velocity and position of particles were updated using Equations (23)–(25), based on DPSO [43]. Then, the algorithm checks allowable range for each particle and new fitness function of the objective function were evaluated. The values of pbest and gbest are obtained and the same procedure was iterated. The obtained gbest value is considered as the solution to the proposed optimization problem.

3. Numerical Examples

In this section, the performance of the proposed handover is obtained using simulation developed by JAVA and the parameters used in this simulation are listed in Table 3.

Table 3. Simulation Parameters.

Parameter	Value
Number of small cells	50
Number of UEs	250
Radius of a macro cell	1000 m
Radius of a small cell	50 m
transmit power of a macro cell	46 dBm
transmit power of a small cell	25 dBm
$RSRP_{th}$	−13.98 dBm
P_{Macro_static}	780 W
P_{Small_static}	21.6 W
P_{Macro_linear}	540 W
P_{Small_linear}	5.4 W
Capacity of a macro cell	500
Capacity of a small cell	25
C_{req_low}	0.05
C_{req_high}	1
TH_{HO}	0.7
Ratio of high rate data traffic	0.5
v_threshold	50 km/h
v_max	100 km/h
L_threshold	0.1
PSO Iteration	500
PSO Swarm Size	3
c_1	0.5
c_2	0.5
r_1	0.5
r_2	0.5

In our numerical examples, we assume two hot spot areas and each hot spot area has randomly deployed 20 small cells. Ten small cells are randomly deployed outside hot spot areas. 80% of UEs are randomly distributed within 40 small cells in hot spot areas and remaining 20% UEs are randomly distributed outside hot spot areas. In numerical examples, HM represents results obtained from the minimization of the number of handovers and EM represents results obtained from the minimization of energy consumption of BSs.

Figure 8 shows the number of handovers and total energy consumption of BSs for varying the number of UEs in a macro cell. As shown in Figure 8, the number of handovers and total energy consumption of BSs in both the CAC-based handover and the proposed handover schemes increase as the number of UEs in a macro cell increases since more UEs result in more handovers and more energy consumption. The number of handovers of the proposed handover scheme is smaller than that of the CAC-based handover in both handover minimization and energy minimization. This is because a UE with low speed and low rate data traffic can be managed by a macro cell and results in the reduction of handovers. Also, the total energy consumption of the proposed handover scheme is smaller than that of the CAC-based handover in both handover minimization and energy minimization. This is because a UE with low speed and low rate data traffic can be managed by a macro cell and more small cells can be turned off to save energy. Both CAC-based handover and the proposed handover have smaller number of handovers when handover minimization is applied than those when energy minimization is applied, respectively. However, both CAC-based handover and the proposed handover have smaller total energy consumption when energy minimization is applied than those when handover minimization is applied. These results show that the proposed handover scheme can efficiently reduce either the number of handovers or the total energy consumption by applying either handover minimization or energy minimization depending on the objective of the application.

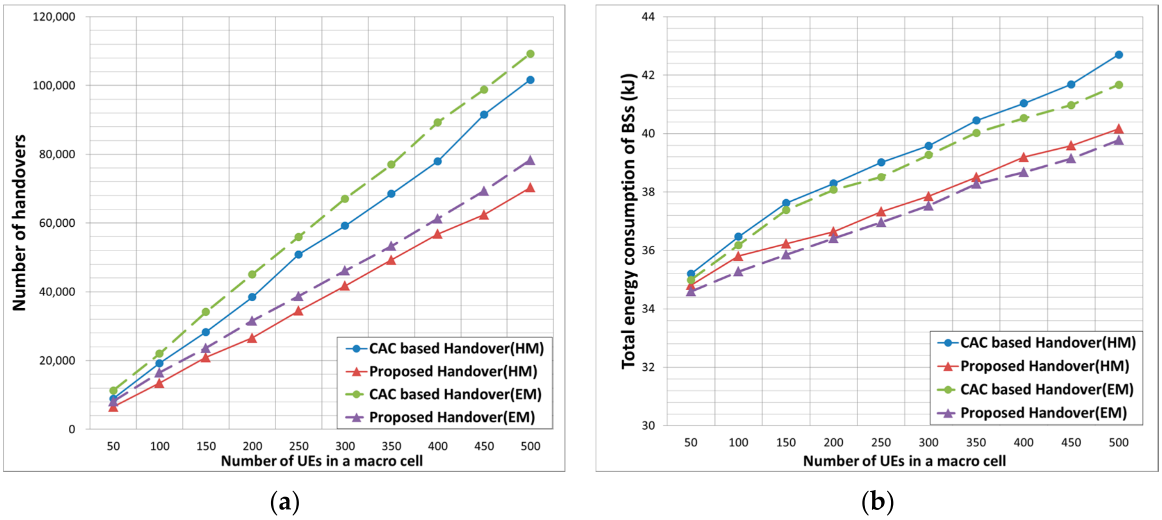
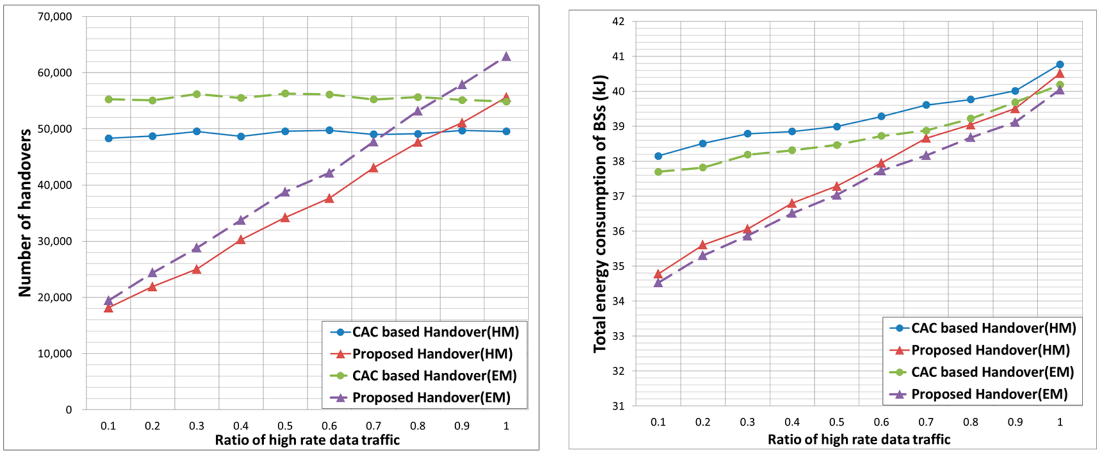


Figure 8. (**a**) Number of handovers for varying number of UEs in a macro cell; (**b**) Total energy consumption of BSs for varying number of UEs in a macro cell.

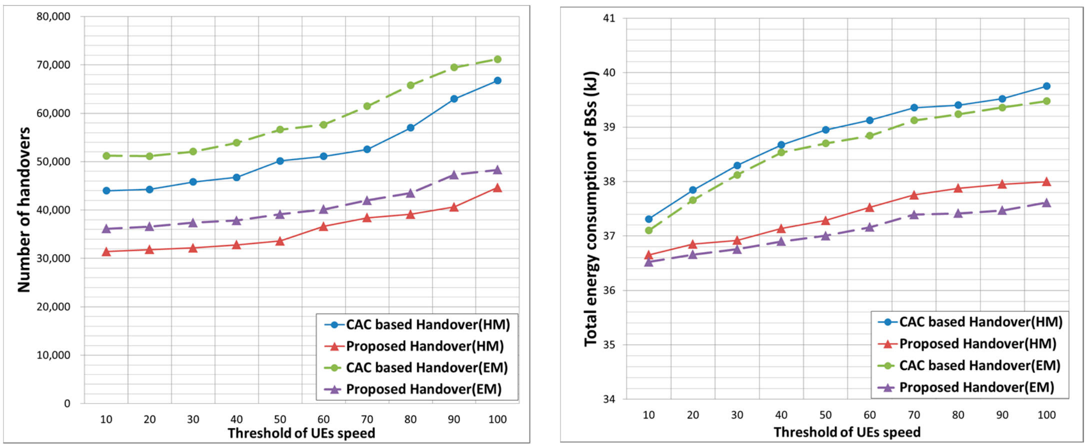
Figure 9 shows the number of handovers and total energy consumption of BSs for varying the ratio of high rate data traffic. In the CAC-based handover scheme, the number of handover does not depend on the ratio of high rate data traffic, since in the CAC-based handover scheme the handover target cell decision depends on the RSRP, the speed of UE, and the capacity and traffic load of BS and it does not depend on the type of data traffic. In the proposed handover scheme, the handover target cell decision depends on the type of data traffic. Therefore, if the ratio of high rate data traffic is low, most of the data traffic are managed by a macro cell and the number of optimal handovers is small. The number of handovers in the proposed handover scheme increases as the ratio of high rate data traffic increases since more data traffic are managed by small cells and there are more handovers. If the ratio of high rate data traffic is very high, the number of handovers of the proposed handover scheme is higher than that of the CAC-based handovers due to frequent handovers since high rate data traffic is managed by small cells in the proposed handover scheme. In Figure 9, similar to the results in Figure 8, both CAC-based handover and the proposed handover have smaller number of handovers when handover minimization is applied than those when energy minimization is applied, respectively. From the aspect of total energy consumption, both CAC-based handover and the proposed handover have higher energy consumption for higher ratio of high rate data traffic since high rate data traffic consumes larger power than low rate data traffic. The proposed handover scheme has smaller total energy consumption than CAC-based handover since the proposed handover efficiently manages low rate data traffic and high rate data traffic in a macro cell and small cells, and can achieve more power saving. The energy saving is more significant if the ratio of high rate data traffic is lower since a UE with low speed and low rate data traffic can be managed by an always-on macro cell in the proposed handover scheme and thus results in more energy saving. Both CAC-based handover and the proposed handover have smaller total energy consumption when energy minimization is applied than those when handover minimization is applied.



(**a**) (**b**)

Figure 9. (**a**) Number of handovers for varying ratio of high rate data traffic; (**b**) Total energy consumption of BSs for varying ratio of high rate data traffic.

Figure 10 shows the number of handovers and total energy consumption of BSs for varying the threshold of UEs speed. The number of handovers in both CAC-based handover and the proposed handover increases as the threshold of UEs speed increases since higher value of threshold of UEs speed results in more UEs managed by small cells in CAC-based handover and the proposed handover schemes. The proposed handover scheme has less number of handovers since a UE with low speed and low rate data traffic can be managed by a macro cell and results in the reduction of handovers. Both CAC-based handover and the proposed handover have a smaller number of handovers when handover minimization is applied than those when energy minimization is applied, respectively.



(**a**) (**b**)

Figure 10. (**a**) Number of handovers for varying threshold of UEs speed; (**b**) Total energy consumption of BSs for varying threshold of UEs speed.

From the aspect of total energy consumption, both CAC-based handover and the proposed handover have higher energy consumption for higher threshold of UEs speed since higher value of threshold of UEs speed results in more UEs managed by small cells in CAC-based handover and the proposed handover schemes and less small cells can be turned off. The proposed handover scheme has smaller total energy consumption than CAC-based handover since the proposed handover efficiently manages low rate data traffic and high rate data traffic in a macro cell and small cells, and can achieve more power saving. The energy saving is more significant if the ratio of high rate data traffic is higher since a UE with low speed and low rate data traffic can be managed by a always-on macro cell in the proposed handover scheme and the ratio of the UEs with low speed and low rate data traffic increases as the threshold of UEs speed increases. Both CAC-based handover and the proposed handover have smaller total energy consumption when energy minimization is applied than those when handover minimization is applied.

4. Conclusions

In this paper, we have considered a heterogeneous network architecture in 5G networks with separated data and control planes, where a macro cell manages control signals and a small cell manages data. Then, we have proposed an optimized handover scheme based on context information such as RSRP, speed of UE, traffic load, call admission control level, and data type. Optimization problems were formulated with either the number of handovers or total energy consumption as an objective function and constraints related with context information. Since the optimization problem developed is an NP-hard problem, we obtained the solution to the optimization problem using particle swarm optimization, which is a widely used bio-inspired algorithm. Finally, the performance of the proposed handover was compared with call admission control handover, for varying ratio of high rate data traffic, number of UEs in a macro cell, and threshold of UEs speed in a macro cell from the perspective of the number of handovers and total energy consumption. Performance analysis results reveal that the proposed optimized handover performs better than the previous CAC-based handover scheme, from the perspective of the number of handovers and energy consumption. We also show that the proposed handover scheme can efficiently reduce either the number of handovers or the total energy consumption of BSs by applying either handover minimization or energy minimization depending on the objective of the application.

Acknowledgments: The authors would like to thank anonymous reviewers, who greatly improved the quality of this paper. The authors would like to thank Min Wook Kang for his help on the simulation of this paper. This research was supported in part by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (NRF-2014R1A1A1037728).

Author Contributions: Dong Yeong Seo and Yun Won Chung conceived and designed the proposed scheme. Dong Yeong Seo and Yun Won Chung conceived and designed the simulations; Dong Yeong Seo performed the simulations; Dong Yeong Seo and Yun Won Chung analyzed the data; Yun Won Chung wrote the paper. Both authors have read and approved the final manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Webb, M. GeSI (Global e-Sustainability Initiative). In *SMART 2020: Enabling the Low Carbon Economy in the Information Age*; The Climate Group: Lambeth, London, 2008; Available online: http://gesi.org/files/Reports/Smart%202020%20report%20in%20English.pdf (accessed on 23 June 2017).
2. Fehske, A.; Fettweis, G.; Malmodin, J.; Biczok, G. The global footprint of mobile communications: The ecological and economic perspective. *IEEE Commun. Mag.* **2011**, *49*, 55–62. [CrossRef]
3. Hasan, Z.; Boostanimehr, H.; Bhargava, V.K. Green cellular networks: A survey, some research issues and challenges. *IEEE Commun. Surv. Tutor.* **2011**, *13*, 524–540. [CrossRef]
4. Aleksic, S. Energy, entropy, and exergy in communication networks. *Entropy* **2013**, *15*, 4484–4503. [CrossRef]
5. Chiaraviglio, L.; Ciullo, D.; Meo, M.; Marsan, M.A. Energy-aware UMTS access networks. In Proceedings of the International Symposium on Wireless Personal Multimedia Communications (WPMC), Lapland, Finland, 8–11 September 2008; p. 105.
6. Marsan, M.A.; Chiaraviglio, L.; Ciullo, D.; Meo, M. Optimal energy savings in cellular access networks. In Proceedings of the IEEE International Conference on Communications Workshops (ICCW), Dresden, Germany, 14–18 June 2009.
7. Peng, C.; Lee, S.B.; Lu, S.; Luo, H. GreenBSN: Enabling energy-proportional cellular base station network. *IEEE Trans. Mob. Comput.* **2014**, *13*, 2537–2551. [CrossRef]

8. Bousia, A.; Kartsakli, E.; Alonso, L.; Verikoukis, C. Dynamic energy efficient distance-aware base station switch On/Off scheme for LTE-advanced. In Proceedings of the IEEE Global Communications Conference (GLOBECOM), Anaheim, CA, USA, 3–7 December 2012; pp. 1532–1537.
9. Bousia, A.; Antonopoulos, A.; Alonso, L.; Verikoukis, C. "Green" distance-aware base station sleeping algorithm in LTE-Advanced. In Proceedings of the IEEE International Conference on Communications (ICC), Ottawa, ON, Canada, 10–15 June 2012; pp. 1347–1351.
10. Chang, C.Y.; Liao, W.; Shiu, D. On the coverage preservation problem in green cellular networks. In Proceedings of the IEEE Global Communications Conference (GLOBECOM), Anaheim, CA, USA, 3–7 December 2012; pp. 3496–3501.
11. Oh, E.; Son, K.; Krishnamachari, B. Dynamic base station switching-On/Off strategies for green cellular networks. *IEEE Trans. Wirel. Commun.* **2013**, *12*, 2126–2136. [CrossRef]
12. Niu, Z.; Wu, Y.; Gong, J.; Yang, Z. Cell zooming for cost-efficient green cellular networks. *IEEE Commun. Mag.* **2010**, *48*, 74–79. [CrossRef]
13. Niu, Z. Tango: Traffic-aware network planning and green operation. *IEEE Wirel. Commun. Mag.* **2011**, *18*, 25–29. [CrossRef]
14. Ashraf, I.; Boccardi, F.; Ho, L. Sleep mode techniques for small cell deployments. *IEEE Commun. Mag.* **2011**, *49*, 72–79. [CrossRef]
15. Saker, L.; Elayoubi, S.E.; Combes, R.; Chahed, T. Optimal control of wake up mechanisms of femtocells in heterogeneous networks. *IEEE J. Sel. Areas Commun.* **2012**, *30*, 664–672. [CrossRef]
16. Wildemeersch, M.; Quek, T.Q.S.; Slump, C.H.; Rabbachin, A. Cognitive small cell networks: Energy efficiency and trade-offs. *IEEE Trans. Commun.* **2013**, *61*, 4016–4029. [CrossRef]
17. Lee, K.S.; Kim, H.S.; Kim, Y.T.; Kim, B.H. DANCE: Small AP On/Off algorithms in ultra dense wireless network. *J. Korean Inst. Commun. Inf. Sci.* **2013**, *38*, 1135–1144. [CrossRef]
18. Feng, M.; Mao, S.; Jiang, T. BOOST: Base station On-Off switching strategy for energy efficient massive MIMO HetNets. In Proceedings of the 35th Annual IEEE International Conference on Computer Communications (INFOCOM), San Francisco, CA, USA, 10–15 April 2016; pp. 1395–1403.
19. Cai, S.; Che, Y.; Duan, L.; Wang, J.; Zhou, S.; Zhang, R. Green 5G heterogeneous networks through dynamic small-cell operation. *IEEE J. Sel. Areas Commun.* **2016**, *34*, 1103–1115. [CrossRef]
20. Feng, M.; Mao, S.; Jiang, T. Base station On-Off switching in 5G wireless networks: Approaches and challenges. *arXiv*, 2017, arXiv:1703.09875.
21. Liu, C.; Natarajan, B.; Xia, H. Small cell base station sleep strategies for energy efficiency. *IEEE Trans. Veh. Technol.* **2016**, *65*, 1652–1661. [CrossRef]
22. Guo, X.; Niu, Z.; Zhou, S.; Kumar, P.R. Delay-constrained energy-optimal base station sleeping control. *IEEE J. Sel. Areas Commun.* **2016**, *34*, 1073–1085. [CrossRef]
23. Wu, J.; Wong, E.W.M.; Guo, J.; Zukerman, M. Performance analysis of green cellular networks with selective base-station sleeping. *Perform. Eval.* **2017**, *111*, 17–36. [CrossRef]
24. Antonopoulos, A.; Kartsakli, E.; Bousia, A.; Alonso, L.; Verikoukis, C. Energy-efficient infrastructure sharing in multi-operator mobile networks. *IEEE Commun. Mag.* **2015**, *53*, 242–249. [CrossRef]
25. Oikonomakou, M.; Antonopoulos, A.; Alonso, L.; Verikoukis, C. Cooperative base station switching off in multi-operator shared heterogeneous network. In Proceedings of the IEEE Global Communications Conference 2015 (GLOBECOM), San Diego, CA, USA, 6–10 December 2015; pp. 1–6.
26. Lee, S.; Moon, S.; Yi, Y. On greening cellular networks by sharing base stations: A game-theoretic approach. In Proceedings of the 9th EAI International Conference on Performance Evaluation Methodologies and Tools (VALUETOOLS), Berlin, Germany, 14–16 December 2015; pp. 87–94.
27. Bousia, A.; Kartsakli, E.; Antonopoulos, A.; Alonso, L.; Verikoukis, C. Multiobjective auction-based switching-off scheme in heterogeneous networks: To bid or not to bid? *IEEE Trans. Veh. Technol.* **2016**, *65*, 9168–9180. [CrossRef]
28. Bousia, A.; Kartsakli, E.; Antonopoulos, A.; Alonso, L.; Verikoukis, C. Game-theoretic infrastructure sharing in multioperator cellular networks. *IEEE Trans. Veh. Technol.* **2016**, *65*, 3326–3341. [CrossRef]
29. Roessler, A.; Schlienz, J.; Merkel, S.; Kottkamp, M. *LTE-Advanced (3GPP Rel.12) Technology Introduction*; White Paper; Rohde and Schwarz: Munich, Germany, 2014; Available online: http://www.rohde-schwarz-usa.com/rs/324-UVH-477/images/1MA252_WP_LTE_Rel12_1E.pdf?aliId (accessed on 23 June 2017).

30. He, G.; Zhang, S.; Chen, Y.; Xu, S. Architecture design and performance evaluation for future green small cell wireless networks. In Proceedings of the 2013 IEEE International Conference on Communications, Budapest, Hungary, 9–13 June 2013; pp. 1178–1182.
31. Ishii, H.; Kishiyama, Y.; Takahashi, H. A novel architecture for LTE-B: C-plane/U-plane split and phantom cell concept. In Proceedings of the 2012 IEEE Globecom Workshops, Anaheim, CA, USA, 3–7 December 2012; pp. 624–630.
32. Zhang, S.; Wu, J.; Gong, J.; Zhou, S.; Niu, Z. Energy-optimal probabilistic base station sleeping under a separation network architecture. In Proceedings of the 2014 IEEE Global Communications Conference (GLOBECOM), Austin, TX, USA, 8–12 December 2014.
33. Wang, Z.; Zhang, W. A separation architecture for achieving energy-efficient cellular networking. *IEEE Trans. Wirel. Commun.* **2014**, *13*, 3113–3123. [CrossRef]
34. Zhang, S.; Gong, J.; Zhou, S.; Niu, Z. How many small cells can be turned off via vertical offloading under a separation architecture? *IEEE Trans. Wirel. Commun.* **2015**, *14*, 5440–5453. [CrossRef]
35. Badri, T.F.Z.; Saadane, R.; Wahbi, M.; Mbarki, S. Call admission control scheme for LTE femtocell-macrocell integrated system. In Proceedings of the 2014 IEEE International Conference on Multimedia Computing and Systems (ICMCS), Marrakech, Morocco, 14–16 April 2014.
36. Boujelben, M.; Rejeb, S.B.; Tabbane, S. A novel green handover self-optimization algorithm for LTE-A/5G HetNets. In Proceedings of the 2015 International IEEE Wireless Communications and Mobile Computing Conference (IWCMC), Dubrovnik, Croatia, 24–28 August 2015.
37. Sung, N.W.; Pham, N.T.; Huynh, T.; Hwang, W.J.; You, I.S.; Choo, K.K.R. Prediction-based association control scheme in dense femtocell networks. *PLoS ONE* **2017**, *12*, e0174220. [CrossRef] [PubMed]
38. Kanwal, K.; Safdar, G.A. Reduced early handover for energy saving in LTE networks. *IEEE Commun. Lett.* **2016**, *20*, 153–156. [CrossRef]
39. Roy, A.; Da, S.K.; Misra, A. Exploiting information theory for adaptive mobility and resource management in future cellular networks. *IEEE Wirel. Commun.* **2004**, *11*, 58–65. [CrossRef]
40. Wang, L.; Kofman, D.; Binet, D. Towards a framework of network selection in heterogeneous wireless networks. In Proceedings of the 5th EuroNF Workshop on Wireless & Mobility, Stockholm, Sweden, 23–24 October 2008; pp. 1–6.
41. Seo, D.Y.; Chung, Y.W. A novel handover scheme based on context information in 5G networks. *World J. Wirel. Devices Eng.* **2017**, *1*, 45–50. [CrossRef]
42. Kennedy, J.; Eberhart, R. Particle swarm optimization. In Proceedings of the IEEE International Conference on Neural Networks, Perth, Australia, 27 November–1 December 1955; Volume 4, pp. 1942–1948.
43. Zhang, W.; Kwak, K.S.; Feng, C. Network selection algorithm for heterogeneous wireless networks based on multi-objective discrete particle swarm optimization. *KSII Trans. Internet Inf. Syst.* **2012**, *6*, 1802–1814. [CrossRef]
44. You, I.S.; Sharma, V.; Atiquzzaman, M.; Choo, K.K.R. GDTN: Genome-based delay tolerant network formation in heterogeneous 5G using inter-UA collaboration. *PLoS ONE* **2016**, *11*, e0167913. [CrossRef] [PubMed]
45. Shahid, A.; Aslam, S.; Lee, L.G. A decentralized heuristic approach towards resource allocation in femtocell networks. *Entropy* **2013**, *15*, 2524–2547. [CrossRef]
46. Hu, W.; Liang, H.; Peng, C.; Du, B.; Hu, Q. A hybrid chaos-particle swarm optimization algorithm for the vehicle routing problem with time window. *Entropy* **2013**, *15*, 1247–1270. [CrossRef]
47. Alsharif, M.H.; Nordin, R.; Ismail, M. Cell-coverage-area optimization based on particle swarm optimization (PSO) for green macro long-term evolution (LTE) cellular networks. In *Bio-Inspired Computation in Telecommunications*; Morgan Kaufmann: Waltham, MA, USA, 2015; Chapter 11; pp. 245–262.