Energy Conservation Schemes Based on Mobility Modeling in Small Cell Networks

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Abstract

Traditional mobile networks will become dual-layer wireless networks due to small cells deployment. In the next generation of wireless mobile communications, it can be visualized that heterogeneous networks, including macro cells, micro cells and pico cells, are demanded to cooperate user-friendly in a seamless manner. One of the key factors for network cooperation is mobility of users, which causes disproportional distributions of traffic load in time-space domain. In the paper, a new mobility model is raised and analyzed by Markov theory. Furthermore, a novel energy conservation scheme based on the mobility model is proposed. Energy efficiency is improved through the deployment of sleeping strategies among small cells. And an optimized method is given to reduce energy consumption, on condition that users' demands are satisfied. Finally, the validity of energy saving scheme is verified by simulations. The numerical results show that energy consumption could be reduced about 12%.

1. Introduction

With the rapid development of mobile Internet services, the traditional wireless networks are faced with large challenges. As data services are increasingly visited by mobile terminal users, traffic load of wireless communication networks is rising rapidly. In the next generation of wireless mobile communications, it can be visualized that heterogeneous networks are demanded to cooperate in a seamless manner. The eMobility European technology platform (ETP) of the seventh European framework program [1], which is a community of more than 650 European member organizations to address the challenges of future networks in mobile communications, indicates that convergence of wireless and Internet networks is the trend of future wireless communications. Mobile communications industry is now grasping the opportunity to add mobility to Internet accessibility, effectively allowing citizens to carry the power of the Internet with them anywhere at any time and the convergence of wireless and Internet usage is already underway 0. The main target is to satisfy users' requirements and improve utilization efficiency of radio resources.

It is one of the main reasons that the disproportional distribution of mobile users and services in time and space domain for performance reduction in hotspots, as well as radio resource waste in other districts [2]. The variation of mobile user distribution is described by original data collected from cellular networks in a southern city of China, recording mobile user distribution by dividing the city into thousands of pixels, as shown in Fig.1. On the other hand, as more and more small cells deployed, energy saving should take into consideration [3]. However, network management mechanisms are not effective on solving this problem presently. There is an opportunity to overcome this difficulty by raising a new energy conservation scheme.

The remainder of this paper is organized as follows. Section 2 describes the system model of small cell networks. In section 3, a mobility model is proposed to describe users' mobility status in cellular networks. Section 4 raises a smart cooperation scheme for energy saving. Simulation results and performance analysis are given in section 5. Finally, Section 6 concludes the paper.

Fig.1. Distribution of mobile users in a southern city of China

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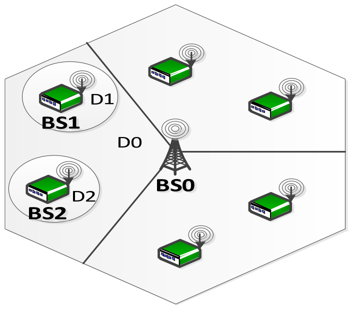
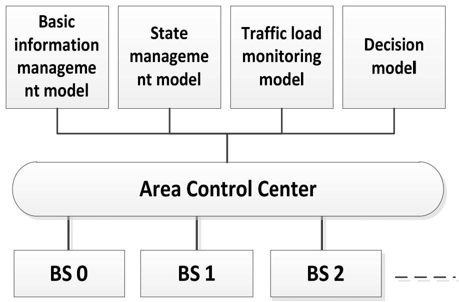
2. System Model

Small cells usually overlay with macro cells. In this section, Fig.2(a) gives the small cell networks scene. Here, BS0 is a macro base station, and area covered by BS0 is named as D0. It is assumed that there are 2 small cell base stations deployed in D0, named as BS1 and BS2. Of course, the number of small cells is not limited to two. The form of those small cells could be different, such as micro cell, pico cell, femto cell, etc.

In this paper, the macro base station and small cell base stations overlaid a certain area are controlled by an Area Control Center (ACC), as shown in Fig.2(b). ACC could be deployed in Mobility Management Entity (MME) in Long Term Evolution (LTE) system. There are 4 models in ACC. They are basic information management model, state management model, traffic load monitoring model, and decision model. The basic information management model is responsible for storing and updating basic information of base stations, including position, power limitation, backhaul ability, etc. The state management model is in charge of storing and updating the working states of base stations, i.e. open or sleep. The traffic monitoring model takes charge with monitoring the traffic of base stations, and storing the history records of traffic load. The decision model answers for deciding the operating status of base stations, including open, sleep, transmit power, etc. The decision algorithms will be described in the rest of the article.



(a) Small cell networks scene



(b) Control module in small cell networks

Fig.2. System model of small cell networks

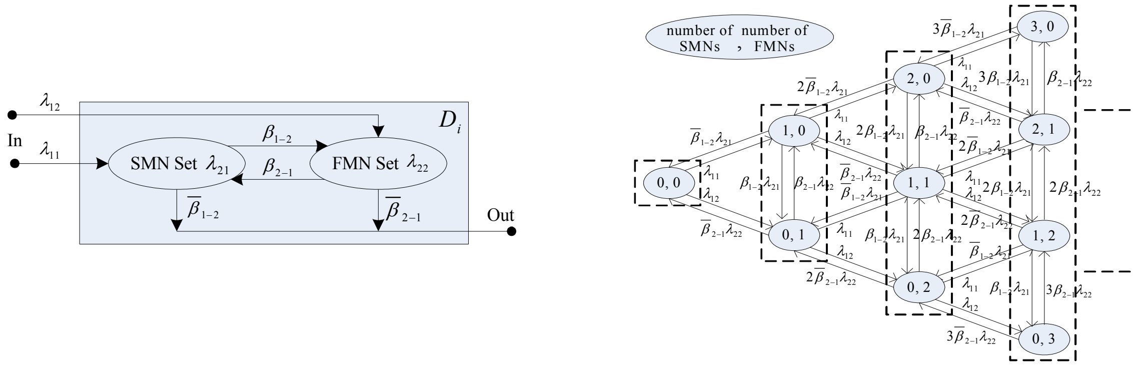
3. Mobility Model

For performance evaluation of small cell networks, mobility model is necessary for traffic analysis in space-time domain. In the section, a Mobility Model based on Velocity Classification (MM-VC) is given. Compared with general mobility models, MM-VC is more closed to circumstances in realistic context. So it is more accurate for parameter configuration based on history data in simulations.

It is obvious that there are different mobility characteristics between motor vehicle users and pedestrian users. Therefore, MNs in classified into 2 groups according to their mobility state in MM-VC, i.e. motor vehicle mobile nodes and non-vehicle mobile nodes. Taken MNs in area Di as an example, they are divided into 2 kinds according to a velocity boundary of v_{i0}, i.e. slower mobile nodes (SMN, $\overline{v}_{SMN} < v_{i0}$) and faster mobile nodes (FMN, $\overline{v}_{FMN} \geq v_{i0}$), as shown in Fig.3(a). It is assumed that the process of MNs arriving to Di is independent of each other. Assuming arrival process of SMNs(FMNs) to be Poisson process, time interval of arriving between adjacent SMNs(FMNs) obeys exponent distribution with rate parameter of λ_{11} (λ_{12}). And cell resident time of SMNs and FMNs have phase-type (PH) distributions, i.e. (α_S, T, T^0) and (α_F, T, T^0) respectively. Here, $(\cdot)^T$ is transpose operations of a matrix, and parameter definitions are given in equation (1). As shown in Fig.3(a), SMNs(FMNs) converts to FMNs(SMNs) in a probability of β_{1-2} (β_{2-1}), and leaves area D_i in a probability of $\overline{\beta}_{1-2}$ ($\overline{\beta}_{2-1}$).

$$\alpha_S = (1,0),\ \alpha_F = (0,1),\ T = \begin{pmatrix} -\lambda_{21} & \beta_{1-2}\lambda_{21} \\ \beta_{2-1}\lambda_{22} & -\lambda_{22} \end{pmatrix},\ T^0 = (\overline{\beta}_{1-2}\lambda_{21}, \overline{\beta}_{2-1}\lambda_{22})^T \tag{1}$$

PH distributions are highly versatile stochastic models that can be used to approximate the distribution of any nonnegative random variables and, at the same time, enjoy analytical tractability due to their underlying Markovian structure. Therefore, the advantage of PH distribution is that it can be decomposed into multiple of negative exponent distributions, which can be analyzed by Markov theory. Fig.3(b) gives a bi-dimensional Markov chain of MM-VC. This Markov model can be solved by matrix-geometric analytic method, which is discussed in [4].



(a) Mobility model based on velocity classification **(b) Bi-dimensional Markov chain of MM-VC**

Fig.3. Mobility model in small cell networks

4. Energy Saving Scheme

Assuming there are I small cells in a macro cell. As shown in Fig.2(a), the macro cell base station is named as BS0, and the small cell base stations are named as BSi, $i = 1, 2, \cdots I$. It is assumed that energy consumptions of small cells are equally. So the energy consumption of dual-layer networks at time t in area D0, named as $P_{all}(t)$, is shown in equation (2). Here, P_0 is energy consumption of BS0, and P_i is energy consumption of BSi. $\alpha_i(t)$ is a weight coefficient of BSi. Usually, energy consumption of base station in sleep state is 0.3 times of the full amount.

Suppose that traffic load is $TH_{all}(t)$ at time t in area D0. The throughput of the dual-layer network in this area should satisfy those users' demands. The target is energy conservation on condition that user services should be satisfied. It could be expressed as an optimization problem, as shown in equation (3). Assuming traffic load beared by BS0 is $TH_0(t)$, and traffic load beared by BSi is $TH_i(t)$. $TH_{0\max}$ and $TH_{i\max}$ are throughput capacitis of BS0 and BSi. Here, ω is a redundancy coefficient to ensure that traffic demands would not exceed capability of base stations.

$$P_{all}(t) = P_0 + \sum_{i=1}^{I} P_i \alpha_i(t) \quad , \quad \alpha_i(t) = \begin{cases} 1, & \text{if BS}i \text{ is open} \\ 0.3, & \text{if BS}i \text{ is sleep} \end{cases} \tag{2}$$

$$\begin{aligned} &\min \quad P_{all}(t) = P_0 + \sum_{i=1}^{I} P_i \alpha_i(t) \\ s.t. \quad &(1) \;\; TH_{all}(t) \le TH_0(t) + \sum_{i=1}^{I} \alpha_i(t) TH_i(t) \\ &(2) \;\; TH_0(t) \le TH_{0\max}\,\omega \\ &(3) \;\; TH_i(t) \le TH_{i\max}\,\omega \end{aligned} \tag{3}$$

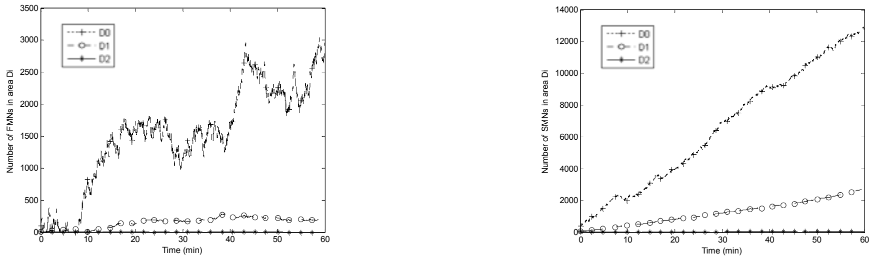
5. Simulation Results

Taken Fig.2 as an example, there are one macro cell and 2 small cells overlapped in area D0. The area covered by BSi, i=1,2, is named as Di. On the ground of the above scene, simulation of users' mobility is done according to MM-VC with $v_{i0} = 30km/h$. Here, values of simulation parameters at 8:00-9:00 are listed in TABLE I as an example. And the simulation results are shown in Fig.4. In this simulation, it is defined that FMNs are all visit services through BS0, and SMNs in area Di visit services through BSi. Then traffic load of each user is supposed to be 2kbps. Throughputs of each BS are shown in Fig.5(a) based on MM-VC simulations of one day, in which simulation parameters are abstracted from statistical data in cellular networks in a city of China. It is shown that busy hours of BS1 are at night, and busy hours of BS2 are in the daytime. The overall throughput in this area is also given in Fig.5(a).

In no-cooperation mode, all of small cells and the macro cell are always open. In cooperation mode, the macro cell is always open. In each hour, small cells are open when BS0 could not afford the traffic load in this area. If the users' traffic demands could be satisfied when one small cell open, the other small cells are sleep. Otherwise, another small cell will be open. The rest may be deduced by analogy. Here, small cells are open in order of traffic load in each cell shown in Fig.5(a). The above method is implemented through the ACC described in section 2. Comparison of no-cooperation mode and cooperation mode are shown in Fig.5(b) and Fig.5(c). Suppose that the energy consumption of macro station is 500W, and that of each small station is 100W. It is assumed that the value of redundancy coefficient ω is 0.8. When throughput capacity of each cell is 150Mbps, the cooperation mode proposed in this section can save energy from 10% to 20% during one day, and average energy saving is 12%.

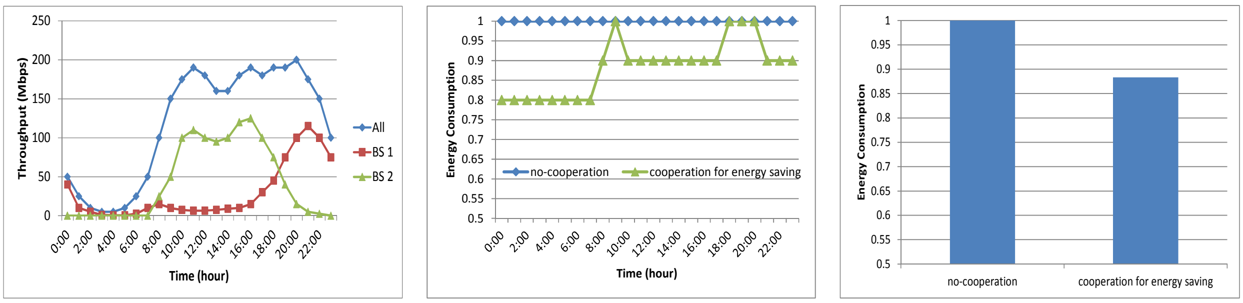
TABLE I Simulation parameters of MM-VC

	λ_{11}	λ_{12}	λ_{21}	λ_{22}	β_{1-2}	β_{2-1}
Area D0	300	600	250	600	0.1	0.3
Area D1	32	40	20	36	0.05	0.9
Area D2	1	1	1	1	0	0



(a) Number of FMNs. **(b) Number of SMNs.**

Fig.4. Simulation results of MM-VC at 8:00-9:00 in area Di



(a) Throughput distribution **(b) Hourly energy consumption** **(c) Average energy consumption**

Fig.5. Simulation results of the energy conversation scheme in area D0

6. Conclusion

In this paper, a system model in small cell networks is proposed, and the Area Control Center (ACC) is used for network cooperation. Then a new mobility model named as MM-VC is raised. Furthermore, a novel cooperation method is proposed for energy saving in small cell networks. Finally, simulation results of energy saving performance are given to show benefits of the network cooperation scheme.

7. References

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