Cooperative and Competitive Effect in Heterogeneous Networks of Healthcare System

Xiaoshuang Liu[1,2], Guixia Kang[2], Ningbo Zhang[2], Yanyan Guo[2]
1. College of information technology, Hebei University of Economics and Business
[LXS_55@163.com]
2. Beijing University of Posts and Telecommunications
[gxkang@bupt.edu.cn]
Beijing, PR China
**Corresponding author: Xiaoshuang Liu*

Received November 11, 2014; revised May 19, 2015; accepted July 7, 2015; published November 30, 2015

Abstract

Different network provides different service. To maximize the profit, heterogeneous networks form a whole, which may either compete or cooperate with each other. In this paper, the healthcare monitor network architecture is introduced to build the competitive and cooperative mechanisms of heterogeneous networks which contain three networks, namely, cellular network, WLAN and WMAN. This paper considers the natural growth rate of the network with competitive and cooperative effects. Then, the stability of the proposed model and its equilibrium points are analyzed by the ordinary differential principle. Finally, simulation results show that the natural growth rate cannot increase the profit of the network, but effective cooperative among heterogeneous networks can increase the profit of each network, and competitive may decrease the profit of each network.

Keywords: Heterogeneous networks, cooperative and competitive, profit, healthcare system.

This work is supported by the Important National Science & Technology Specific Projects of the Ministry of Science and Technology of China (no. 2013ZX03006001), New Century Excellent Talents in University (NCET) (no. NCET-11-0593), the National High Technology Research and Development Program of China ("863" Program, No. SQ2015AA0102085), and National Natural Science Foundation of China (No. NSFC61471064).

http://dx.doi.org/10.3837/tiis.2015.11.008 **ISSN : 1976-7277**

1. Introduction

The rapid proliferation of multi-radio devices and radio access technologies puts forward the challenge of high-speed collaborative transmission over heterogeneous networks. In the last decade, more and more wireless access technologies are embedded in mobile terminals such as Wi-Fi, Bluetooth, UWB and so on [1-2]. At the same time, the applications such as voice, video as well as file transfer need to transmit data simultaneously and some of them are bandwidth-hungry. Therefore heterogeneous wireless access networks (WANs) will be built and will form the wireless overlay access networks to satisfy different mobile users and different applications in the intense-access scenarios, for example, wireless E-health, wireless meeting room, wireless E-education, smart house and so forth.

Mobile, wireless, pervasive computing and communication environments are changing the way medical staffs interact with their patients and the elderly. By deploying self-organized wireless physiological-monitoring hardware/software systems, continual patient monitoring in certain types of patient postures becomes convenient to assuring timely intervention by a healthcare practitioner or a physician [3]. User terminal with multi-network interface is capable of accessing different networks and choose the network with the most suitable QoS (Quality of Service) with the least service costs [4]. Consequently, all the service providers may cooperate or compete to maximize the total profits by attracting more users. To this end, the cooperation and competition among heterogeneous networks has become an important research topic [5-6]. Remote healthcare monitoring has the advantages of reduced medical costs, increased medical quality, continuous and timely patient monitoring, complete patient physical data collection, and timely presenting the correct adaptive remedy. The hierarchical architecture is used in wireless sensor network technology development for healthcare monitoring [7-8].

The authors of [9] proposed three different pricing models, that is, market-equilibrium, competitive, and cooperative pricing models for spectrum trading in a cognitive radio environment. In these pricing models, the primary service providers have different behaviors (i.e., competitive and cooperative behaviors) to achieve different objectives of spectrum trading. Zhou et al. [10] studied the problem of video streaming over multi-channel multi-radio multihop wireless networks, and developed fully distributed scheduling schemes with the goals of minimizing the video distortion and achieving certain fairness. [11] presents a novel framework for delay-sensitive multimedia applications over resource-limited heterogeneous networks by considering multimedia forensics, network adaptation, and deadline-driven scheduling. Particularly, they developed a joint forensics-scheduling scheme, which allocated the available network resources based on the affordable forensics overhead and expected quality of service, adaptively adjusted the scalable media-aware forensics, and scheduled the transmissions to meet the application's sdelay constraints. In [12], H. Chang et al. developed a cooperative spectrum sharing scheme for heterogeneous networks by using a market model, in which they introduced a roaming rate as the incentive for each service provider to gain extra revenue when its licensed users temporarily leverage other service providers' service. Then, they obtained the equilibrium at which all service providers and all licensed users satisfied the amount of the allocated bandwidth and the price simultaneously by using the concept of demand and supply from economics. C. Singh and S Sarkar researched cooperation among service providers among heterogeneous networks, which is modeled by using the theory of transferable payoff coalitional games [13].

With the development of wireless communication technology, a variety of heterogeneous communication technologies provide the users with ubiquitous access to the data networks. In heterogeneous wireless networks, user terminal with multinetwork interface is capable of accessing different networks and choose the network with the most suitable QoS with the least service costs. In such an environment, all the service providers (SPs) compete to maximize their revenue by attracting more users. As a result, severe competition may result in lower product prices and may shrink the total profits of SPs in turn, which may not be desirable for SPs. In that case, SPs may opt to cooperate instead of compete. To this end, the cooperation among heterogeneous networks has become an important research topic.

Hence, a system contains some heterogeneous networks to maximize the profit, where these networks may cooperate and compete with each other. In this system, due to the interactions among networks, the profit maximization problem becomes more complex. The problem formulation, solution techniques, and results of this paper significantly differ from the existing literatures. Our reaserch focuses on cooperative and competitive behaviors among heterogeneous networks, and proposes a healthcare monitor network architecture in heterogeneous wireless sensor networks (HWSN). In such an environment, a differential dynamic model [14] is used to build network cooperation and competition framework among wireless heterogeneous networks to coordinate the inter-behaviors between networks.

The rest of this paper is organized as follows. Section 2 describes the healthcare monitor network architecture, heterogeneous networks and system assumption. Section 3 presents the stability analysis of the cooperative and competitive effect. Section 4 presents the performance evaluation. Finally, Section 5 gives the conclusions of this paper.

2. System Model

2.1. Architecture Overview

There are three tiers in the proposed healthcare architecture. In **Fig. 1**, we depict the details and relationships among the tiers.

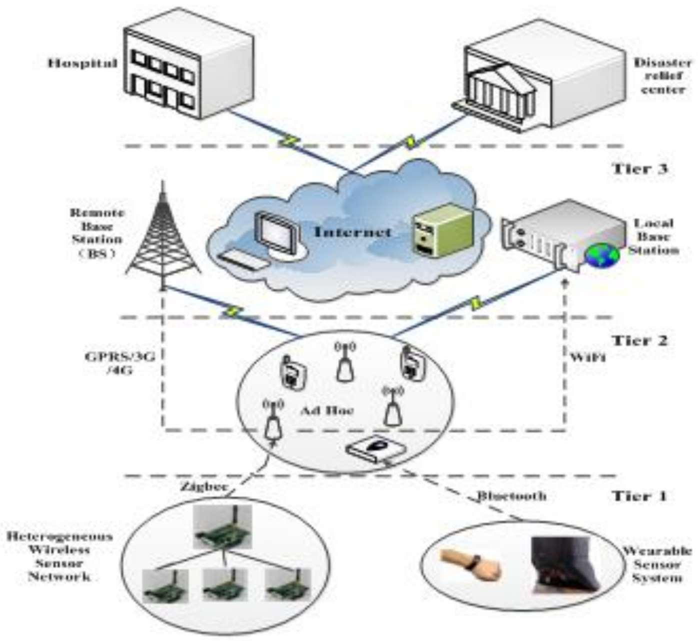


Fig. 1. Healthcare monitor network architecture in Heterogeneous wireless sensor networks.

1) Tier1— Heterogeneous Wireless Sensor Network: Two types of sensor systems for different sensing objectives are designed to capture the individuals' vital signals and the environmental physical parameters in their residence. Wearable sensor systems (WSS) with Bluetooth wireless transmission are integrated with biomedical sensors installed in patient identification wristband or fabric belt. The WSS is conveniently and comfortably tailored to the individual body to capture their physiological data. Two types of heterogeneous sensor nodes are placed in the monitoring area to capture the environmental parameters transmitted through a wired or wireless network, communicating using Zigbee wireless technology. Physical records and parameters from the WSS and HWSN must be transmitted securely to the upper network tier [15].

2) Tier2— Ad Hoc Network: In the healthcare architecture, several wireless routers and mobile terminals (MTs) are organized regionally using an ad hoc network to route with multiple hops or an infrastructure-based network to connect to a fixed remote base station (BS) or local base station. If the BS is destroyed by disasters, the communication command vehicle will be a substitute for the BS. One MT with enough computation capabilities must capture and analyze physical records from the WSS or HWSN because the device does not have mass data storage capability over a long period of time such as a few months or years. However, major or significant data collection storage will be required in the back-end network database through an infrastructure-based mode where one MT can route data to a station. It can also secure the message through public key cryptosystem [16].

3) Tier3— Back-end Network: This tier is structured on the Internet. It has fixed stations and servers to provide application-level services for the low tiers and process various sensing data from numerous MTs. The server-side database stores physical records for long-term periods from monitored individuals and their residence environmental data. Because the integration of various wireless technologies such the cellular network, WLAN, and WMAN, application services can be accessed easily by MTs. A third party set up on the Internet can be trusted to open access areas such as hospitals or nursing homes supporting the proposed healthcare monitoring service. At least one station is necessary to provide MTs and routers connection to the third party. The third party issues effective certificates and keys to valid MTs.

2.2 In nursing-house, in-home applications

The proposed architecture can be implemented in a lot of scenarios. In this section, we illustrate two implemented nursing-house and in-home healthcare scenarios using this architecture. According to the nursing-house example in **Fig. 2** (left), a lot of sensor nodes deployed in a nursing house can form a wired or wireless network. Based on the limited power of sensor nodes, some of them should have a sleep mode to stop automatic monitoring and reporting in order to reduce power consumption. Sensor nodes also can organize an alarm network to forward emergency data over all networks when there is a severe environmental condition. Wearable sensor nodes designed with the Zigbee technology could directly connect to WSNs.

Fig. 2 (right) shows the example of healthcare monitoring applications at home. It is timely for wearable sensor nodes on a monitored individual to obtain physiology signals and transmit them timely to the computing devices which are held by nurses or family members. The WSS monitor the sustained physical postures of the elderly or chronic patients on the computing devices which perform a healthcare analysis process to search for abnormal findings. The application to analyze physical records will be applied in the back-end networks for the analysis quality improvement.

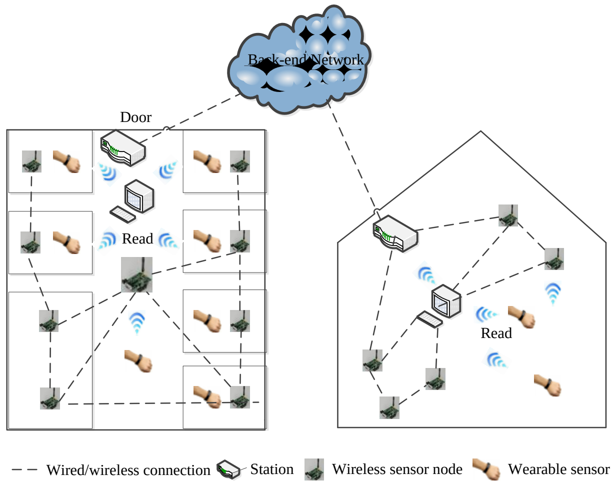


Fig. 2. Healthcare monitoring applications in nursing-house and in-home.

From the analysis of the proposed healthcare monitoring architecture and its applications, we know that how the sensor nodes to deploy in the 3D space is an urgent issue to be solved. In the following section, we investigate a 3D sensing model.

2.2. Heterogeneous Networks

We consider a heterogeneous wireless access environment consisting of CDMA cellular network, IEEE 802.11 WLAN, and IEEE 802.16 WMAN radio interfaces, as shown in **Fig. 3**. A mobile with multiple radio transceivers (for example, software radio) is able to connect to these radio access networks simultaneously. The goal function of this paper is to build the variation model of the network scale, which is a function of the competitive and cooperative effects among heterogeneous networks and its own network natural growth rate. By the proposed model, the dynamics mechanism of the coalition system, that is, the objective law of the development process of the system can be explored.

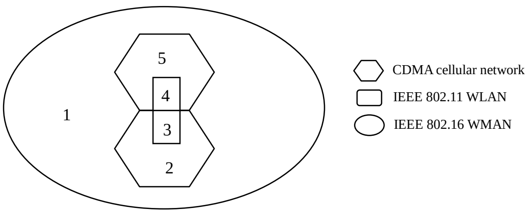


Fig. 3. Service areas under consideration in a heterogeneous wirelessaccess environment.

We consider a geographic region that is entirely covered by a WMAN base station and partly covered by cellular network base stations and partly by WLAN access points (APs), as shown in **Fig. 3**. Users in the different service areas in this region have access to different types and different numbers of wireless networks. In particular, in area 1, only WMAN service is available. In area 2 and area 5, services from cellular networks and WMAN are available. In area 3 and area 4, a mobile can connect to all three types of networks. Different wireless access networks are operated by different service providers. We assume that a mobile is able to connect to each of the networks in the corresponding service area and perfect power control is assumed to ensure a uniform available transmission rate across the coverage area.

In this heterogeneous wireless access network, we assume that multi-interface mobile terminals are able to connect to three different wireless access networks simultaneously. These wireless access networks are CDMA cellular network, IEEE 802.11 WLAN, and IEEE 802.16 WMAN. The price and QoS strategies of a network will determine the number of customers choosing different networks, that is, inducing resource reallocation among networks. In this paper, with the consideration of cooperation and competition, we study how the mobile terminals select from the three networks.

2.3. Assumption

In the heterogeneous wireless access environment, three networks provide the service. We denote network i's ($i=1,2,3$) profit as $p_i(t)$ at time t. Then, $p_i'(t)$ means the profit change rate, and $f_i(p_i(t))=\frac{p_i'(t)}{p_i(t)}$ denotes its instant increment rate. Also, we assume the maximum profit of network i, denoted by m_i.

Firstly, if there is only one network (assume i) providing the service, there are 2 conditions: 1) according to [12], if $m_i \to \infty$, $p_i(t)$ will increase with exponent function with fixed $f_i(p_i(t))$, that is, $p_i'(t)=g\cdot p_i(t)$, where g is the profit growth rate in this condition; 2) if m_i is limited and $m_i \neq p_i(t)$, the profit increase $p_i'(t)$ will become slower and slower with the increase of the profit density, i.e., $\frac{p_i(t)}{m_i}$; 3) if $m_i = p_i(t)$, it ceases to increase. In conclusion, the profit evolvement of network i can be expressed by $p_i'(t)=g\cdot p_i(t)[\frac{m_i-p_i(t)}{m_i}]$. Since $\frac{m_i-p_i(t)}{m_i}=1-\frac{p_i(t)}{m_i}$, it means that $p_i'(t)$ increase (decrease) induced by the decrease (increase) of $\frac{p_i(t)}{m_i}$. Meantime, $p_i'(t)=p_i(t)f_i(p_i(t))$.

Then, if there are three networks provide the service, i.e., network 1, 2, 3, they may either compete or cooperate with each other. Hence, $f_i(p_i(t))$ should be necessarily related to the state variables of 3 networks. Thus, $f_i(p_i(t))$ should be rewritten as $f_i(P)$, where $P=(p_1(t),p_2(t),p_3(t))^T$. Therefore, $\frac{dp_i(t)}{dt}=p_i(t)f_i(P)$.

Cooperation and competition are the inherent attributes of 4G heterogeneous networks system. And the interaction between them drives the self-organization evolvement of the system, and their interaction degree decides the order and stability of the system. Therefore, we introduce two parameters, α_{ij} ($-1\le\alpha_{ij}\le 1$) and β_{ij} ($-1\le\beta_{ij}\le 1$), to indicate the competitive and cooperative effects between two of them induced by resource allocation mode among the three networks. Because the three networks share some common resources, such as spectrum and users, competition for resources occurs among them. Therefore, α_{ij} denotes the competitive effect of network j taking on network i. For example, when they completely share common resources, $\alpha_{ij}=1$; that is, network j takes a large competitive effect on network i. And when they share no common resources, we let $\alpha_{ij}=-1$; that is, network j

takes a large competitive effect on network i. And we let β_{ij} denote the cooperative effect of network j taking on network i. Similarly, $\beta_{ij}=1$ denotes a large cooperative effect of network j taking on network i, and $\beta_{ij}=-1$ indicates negative cooperative effect of network j taking on network i. We use a differential dynamics model [14] to model the profit evolvement of network i. Therefore, the profit evolvement of the competitive and cooperative networks can be written as

$$f_1=\frac{dp_1(t)}{dt}=g_1p_1\left(1-\frac{p_1}{m_1}+\frac{\beta_{12}p_2}{m_2}+\frac{\beta_{13}p_3}{m_3}-\frac{\alpha_{12}p_2}{m_2}-\frac{\alpha_{13}p_3}{m_3}\right), \tag{1}$$

$$f_2=\frac{dp_2(t)}{dt}=g_2p_2\left(1-\frac{p_2}{m_2}+\frac{\beta_{21}p_1}{m_1}+\frac{\beta_{23}p_3}{m_3}-\frac{\alpha_{21}p_1}{m_1}-\frac{\alpha_{23}p_3}{m_3}\right), \tag{2}$$

$$f_3=\frac{dp_3(t)}{dt}=g_3p_3\left(1-\frac{p_3}{m_3}+\frac{\beta_{31}p_1}{m_1}+\frac{\beta_{32}p_2}{m_2}-\frac{\alpha_{31}p_1}{m_1}-\frac{\alpha_{32}p_2}{m_2}\right), \tag{3}$$

where g_i denotes the natural growth rate of profit. Cooperative effect β_{ij} may lead to a positive increase of network scale, while the competitive effect α_{ij} among networks induces its negative increase. Therefore, it is important to study how the network scale varies with the three factors and comes to a stable state, which will be discussed in the next section.

3. Analysis of the Cooperative and Competitive Effect

In this section, we discuss how the network scale varies with the three factors and comes to a stable state. According to the systematic eliminating procedure, the equilibrium points of equation (1)-(3) can be obtained by solving

$$\begin{cases} g_1p_1\left(1-\frac{p_1}{m_1}+\frac{\beta_{12}p_2}{m_2}+\frac{\beta_{13}p_3}{m_3}-\frac{\alpha_{12}p_2}{m_2}-\frac{\alpha_{13}p_3}{m_3}\right)=0 \\ g_2p_2\left(1-\frac{p_2}{m_2}+\frac{\beta_{21}p_1}{m_1}+\frac{\beta_{23}p_3}{m_3}-\frac{\alpha_{21}p_1}{m_1}-\frac{\alpha_{23}p_3}{m_3}\right)=0 \\ g_3p_3\left(1-\frac{p_3}{m_3}+\frac{\beta_{31}p_1}{m_1}+\frac{\beta_{32}p_2}{m_2}-\frac{\alpha_{31}p_1}{m_1}-\frac{\alpha_{32}p_2}{m_2}\right)=0 \end{cases}. \tag{4}$$

Hence, eight equilibrium points are obtained: $q_1(0,0,0)$, $q_2(m_1,0,0)$, $q_3(0,m_2,0)$, $q_4(0,0,m_3)$, $q_5\left(\frac{[1-(\alpha_{12}-\beta_{12})]m_1}{1-(\beta_{12}-\alpha_{12})(\beta_{21}-\alpha_{21})},\frac{[1-(\alpha_{21}-\beta_{21})]m_2}{1-(\beta_{12}-\alpha_{12})(\beta_{21}-\alpha_{21})},0\right)$,

$q_6\left(\frac{[1-(\alpha_{13}-\beta_{13})]m_1}{1-(\beta_{13}-\alpha_{13})(\beta_{31}-\alpha_{31})},0,\frac{[1-(\alpha_{31}-\beta_{31})]m_3}{1-(\beta_{13}-\alpha_{13})(\beta_{31}-\alpha_{31})}\right)$,

$q_7(0,\frac{[1-(\alpha_{23}-\beta_{23})]m_2}{1-(\beta_{23}-\alpha_{23})(\beta_{32}-\alpha_{32})},\frac{[1-(\alpha_{32}-\beta_{32})]m_3}{1-(\beta_{23}-\alpha_{23})(\beta_{32}-\alpha_{32})})$, $q_8(sp_3, vp_3, p_3)$.

For any equilibrium point, the corresponding characteristic matrix(Jacobian Matrix) of evolution equation (4) can be obtained by

$$A=\begin{bmatrix} \partial f_1/\partial p_1 & \partial f_1/\partial p_2 & \partial f_1/\partial p_3 \\ \partial f_2/\partial p_1 & \partial f_2/\partial p_2 & \partial f_2/\partial p_3 \\ \partial f_3/\partial p_1 & \partial f_3/\partial p_2 & \partial f_3/\partial p_3 \end{bmatrix} \tag{5}$$

as

$$A=\begin{bmatrix} g_1(1-\frac{2p_1}{m_1}+\frac{\beta_{12}p_2}{m_2}+\frac{\beta_{13}p_3}{m_3}-\frac{\alpha_{12}p_2}{m_2}-\frac{\alpha_{13}p_3}{m_3}) & g_1p_1(\frac{\beta_{12}}{m_2}-\frac{\alpha_{12}}{m_2}) & g_1p_1(\frac{\beta_{13}}{m_3}-\frac{\alpha_{13}}{m_3}) \\ g_2p_2(\frac{\beta_{21}}{m_1}-\frac{\alpha_{21}}{m_1}) & g_2(1-\frac{2p_2}{m_2}+\frac{\beta_{21}p_1}{m_1}+\frac{\beta_{23}p_3}{m_3}-\frac{\alpha_{21}p_1}{m_1}-\frac{\alpha_{23}p_3}{m_3}) & g_2p_2(\frac{\beta_{23}}{m_3}-\frac{\alpha_{23}}{m_3}) \\ g_3p_3(\frac{\beta_{31}}{m_1}-\frac{\alpha_{31}}{m_1}) & g_3p_3(\frac{\beta_{32}}{m_2}-\frac{\alpha_{32}}{m_2}) & g_3(1-\frac{2p_3}{m_3}+\frac{\beta_{31}p_1}{m_1}+\frac{\beta_{32}p_2}{m_2}-\frac{\alpha_{31}p_1}{m_1}-\frac{\alpha_{32}p_2}{m_2}) \end{bmatrix}. \tag{6}$$

Because Hessian Matrix of A is

$$H=\begin{bmatrix} -\frac{2g_1}{m_1} & 0 & 0 \\ 0 & -\frac{2g_2}{m_2} & 0 \\ 0 & 0 & -\frac{2g_3}{m_3} \end{bmatrix}. \tag{7}$$

And $|H|=-\frac{8g_1g_2g_3}{m_1m_2m_3}<0$, so the saddle point is non-existent.

For the sake of clarity of the discussions, we define

$$A=\begin{bmatrix} a & b & c \\ d & e & f \\ h & i & g \end{bmatrix}. \tag{8}$$

Then, the characteristic equation of matrix A is

$$\lambda^3+k\lambda^2+l\lambda+w=0. \tag{9}$$

where $k=-a-e-g$, $l=ae+ag+eg-ch-bd-if$, $w=che+bdg+ifa-aeg-bfh-cdi$. And its eigenvalues are λ_1, λ_2, λ_3.

According to the ordinary differential principle, the stability of equilibrium points can be judged by the plus or minus sign of k, l, w, or the plus or minus sign of λ_1, λ_2, λ_3. If $k>0$, $w>0$, $kl-w>0$, the equilibrium point is a stable point; otherwise, the equilibrium point is an unstable point.

Next, we will analyze the stability of the competitive and cooperative model.

(1) Input $q_1(0,0,0)$ into A, then A becomes

$$A_1=\begin{bmatrix} g_1 & 0 & 0 \\ 0 & g_2 & 0 \\ 0 & 0 & g_3 \end{bmatrix}. \tag{10}$$

Then, $k=-(g_1+g_2+g_3)<0$. Therefore, $q_1(0,0,0)$ is an unstable point. This shows that when the profit of each network equals to zero, the system is unstable, and this case does not exist.

(2) Input $q_2(m_1,0,0)$ into A, then A becomes

$$A_2=\begin{bmatrix} -g_1 & g_1 m_1(\frac{\beta_{12}}{m_2}-\frac{\alpha_{12}}{m_2}) & g_1 m_1(\frac{\beta_{13}}{m_3}-\frac{\alpha_{13}}{m_3}) \\ 0 & g_2(1+\beta_{21}-\alpha_{21}) & 0 \\ 0 & 0 & g_3(1+\beta_{31}-\alpha_{31}) \end{bmatrix}. \tag{11}$$

Then, $k=g_1-g_2(1+\beta_{21}\text{-}\alpha_{21})-g_3(1+\beta_{31}\text{-}\alpha_{31})$ and $w=-g_1g_2g_3(1+\beta_{21}\text{-}\alpha_{21})(1+\beta_{31}\text{-}\alpha_{31})$. When $1+\beta_{21}\text{-}\alpha_{21}>0$ and $1+\beta_{31}\text{-}\alpha_{31}<0$, then $w>0$. If $k>0$, $kl-w>0$, then $q_2(m_1,0,0)$ is a stable point. Because $1+\beta_{21}\text{-}\alpha_{21}>0$, we can obtain $\beta_{21}>0$, $\alpha_{21}<0$ or $\beta_{21}<0$, $\alpha_{21}>0$ and simultaneously $\beta_{21}\text{-}\alpha_{21}>-1$. This shows that the conditions that the network system is stable are that the cooperative effect on the partner network is bigger than the competitive effect on the partner network or that the competitive effect is so small that it cannot induce the coalition system fluctuation. Because $1+\beta_{31}\text{-}\alpha_{31}<0$, we can obtain $\beta_{31}<0$, $\alpha_{31}>0$ and simultaneously $\beta_{31}\text{-}\alpha_{31}<-1$, which indicate that the competitive negative effect of network 1 taking on network 3 is larger than the cooperative positive effect of network 1 taking on network 3. From the profit of three networks, $(m_1,0,0)$, we can see that an excessive competition between network 1 and network 3 makes no increase of profit for network 1 while the profit of network 2 and 3 is 0.

(3) Input $q_3(0,m_2,0)$, $q_4(0,0,m_3)$ into A, then we can get the similar results as shown in (2).

(4) Input

$q_5(\frac{[1-(\alpha_{12}-\beta_{12})]m_1}{1-(\beta_{12}-\alpha_{12})(\beta_{21}-\alpha_{21})},\frac{[1-(\alpha_{21}-\beta_{21})]m_2}{1-(\beta_{12}-\alpha_{12})(\beta_{21}-\alpha_{21})},0)$ into A, then A becomes

$$A_3 = \begin{bmatrix} B & C & D \\ E & F & G \\ 0 & 0 & H \end{bmatrix}, \tag{12}$$

where $B = \dfrac{-g_1(1+\beta_{12}-\alpha_{12})}{1-(\beta_{12}-\alpha_{12})(\beta_{21}-\alpha_{21})}$, $C = \dfrac{g_1 m_1}{m_2} \times \dfrac{(\beta_{12}-\alpha_{12})[1+(\beta_{12}-\alpha_{12})]}{1-(\beta_{12}-\alpha_{12})(\beta_{21}-\alpha_{21})}$,
$D = \dfrac{g_1 m_1}{m_3} \times \dfrac{(\beta_{13}-\alpha_{13})[1-(\beta_{12}-\alpha_{12})]}{1-(\beta_{12}-\alpha_{12})(\beta_{21}-\alpha_{21})}$, $E = \dfrac{g_2 m_2}{m_1} \times \dfrac{(\beta_{12}-\alpha_{12})[1-(\beta_{21}-\alpha_{21})]}{1-(\beta_{12}-\alpha_{12})(\beta_{21}-\alpha_{21})}$,
$F = \dfrac{-g_2(1+\beta_{21}-\alpha_{21})}{1-(\beta_{12}-\alpha_{12})(\beta_{21}-\alpha_{21})}$, $G = \dfrac{g_2 m_2}{m_3} \times \dfrac{(\beta_{23}-\alpha_{23})[1-(\beta_{21}-\alpha_{21})]}{1-(\beta_{12}-\alpha_{12})(\beta_{21}-\alpha_{21})}$, and
$H = g_3 + g_3 \dfrac{(1+\beta_{12}-\alpha_{12})(\beta_{31}-\alpha_{31})+(1+\beta_{21}-\alpha_{21})(\beta_{32}-\alpha_{32})}{1-(\beta_{12}-\alpha_{12})(\beta_{21}-\alpha_{21})}$.

Then, we obtain

$$k = g_3 + \frac{(1+\beta_{12}-\alpha_{12})[g_1+g_3(\beta_{31}-\alpha_{31})]+(1+\beta_{21}-\alpha_{21})\left[g_2+g_3(\beta_{32}-\alpha_{32})\right]}{1-(\beta_{12}-\alpha_{12})(\beta_{21}-\alpha_{21})},$$

$$w = \frac{(g_1 g_2)^2 g_3\{(1+\beta_{12}-\alpha_{12})(1+\beta_{21}-\alpha_{21})-(\beta_{12}-\alpha_{12})^2[1-(\beta_{21}-\alpha_{21})^2]\}[1-(\beta_{12}-\alpha_{12})(\beta_{21}-\alpha_{21})+(1+\beta_{12}-\alpha_{12})(\beta_{31}-\alpha_{31})+(1+\beta_{21}-\alpha_{21})(\beta_{32}-\alpha_{32})]}{[1-(\beta_{12}-\alpha_{12})(\beta_{21}-\alpha_{21})]^3}.$$

In this case, the profit of two networks is, respectively, given by $p_1 = \dfrac{\left[1-(\alpha_{12}-\beta_{12})\right]m_1}{1-(\beta_{12}-\alpha_{12})(\beta_{21}-\alpha_{21})}$, and $p_2 = \dfrac{\left[1-(\alpha_{21}-\beta_{21})\right]m_2}{1-(\beta_{12}-\alpha_{12})(\beta_{21}-\alpha_{21})}$.

If $k>0$, $kl-w>0$, then q_5 is a stable point. This shows that the network system is stable, and the cooperative effect on the partner network is bigger than the competitive effect on the partner network or that the competitive effect is so small that it cannot induce the coalition system fluctuation. Because $p_1 > m_1$ and $p_2 > m_2$, then $p_1 + p_2 > m_1 + m_2$.

(5) Input q_6, q_7 into A, then we can get the similar results as shown in (4).

(6) Input $q_8(sp_3, vp_3, p_3)$ into A, then A becomes

$$A = \begin{bmatrix} g_1 - g_1 p_3(\frac{2s}{m_1}+\frac{\beta_{12}v}{m_2}+\frac{\beta_{13}}{m_3}-\frac{\alpha_{12}v}{m_2}-\frac{\alpha_{13}}{m_3}) & g_1 s p_3(\frac{\beta_{12}}{m_2}-\frac{\alpha_{12}}{m_2}) & g_1 s p_3(\frac{\beta_{13}}{m_3}-\frac{\alpha_{13}}{m_3}) \\ g_2 v p_3(\frac{\beta_{21}}{m_1}-\frac{\alpha_{21}}{m_1}) & g_2 - g_2 p_3(\frac{2v}{m_2}+\frac{\beta_{21}s}{m_1}+\frac{\beta_{23}}{m_3}-\frac{\alpha_{21}s}{m_1}-\frac{\alpha_{23}}{m_3}) & g_2 v p_3(\frac{\beta_{23}}{m_3}-\frac{\alpha_{23}}{m_3}) \\ g_3 p_3(\frac{\beta_{31}}{m_1}-\frac{\alpha_{31}}{m_1}) & g_3 p_3(\frac{\beta_{32}}{m_2}-\frac{\alpha_{32}}{m_2}) & g_3 - g_3 p_3(\frac{2}{m_3}+\frac{\beta_{31}s}{m_1}+\frac{\beta_{32}v}{m_2}-\frac{\alpha_{31}s}{m_1}-\frac{\alpha_{32}v}{m_2}) \end{bmatrix}.$$

Then, we obtain k and w. If $k>0$, $kl-w>0$, then q_8 is a stable point. This shows that the network system is stable, and the cooperative effect on the partner network is bigger than the competitive effect on the partner network or that the competitive effect is so small that it cannot induce the coalition system fluctuation. Otherwise, q_8 is a saddle point. It shows that the competitive effect of the system is larger than the cooperative effect. In this case, the system is unstable.

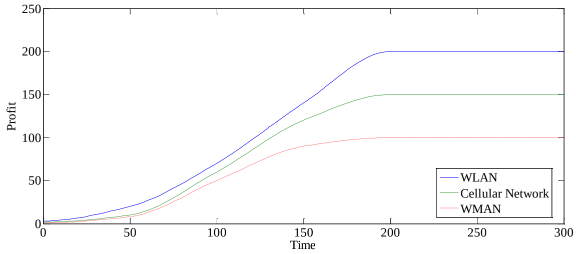
5. Simulation Results

In this paper, we give a series of simulation experiments with Matlab to verify the validity of the analysis. We assume that the length of the cube monitoring area is $100m$, and there are 85 sensor nodes in the area randomly. The radius of sensor nodes is $R = 20m$.

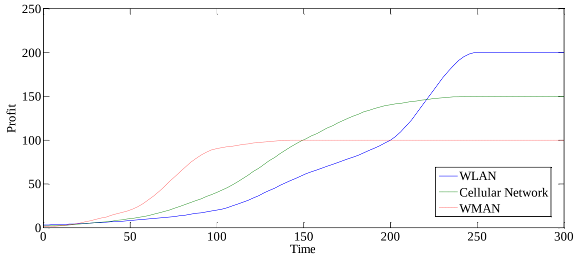
In this set of experiments, we assume that the maximum profits of WLAN, cellular network and WMAN are 200, 150 and 100, respectively, in a non-cooperative scheme where each service provider serves its licensed users with all of its bandwidth, that is, $m_1 = 200$, $m_2 = 150$ and $m_3 = 100$. **Fig. 4** shows the profit evolving curves with time for WLAN, cellular network and WMAN with different natural growth rates (i.e., r_1, r_2 and r_3) under the conditions of noncooperation and noncompetition, that is,

$$\alpha_{12} = \beta_{12} = \alpha_{21} = \beta_{21} = \alpha_{13} = \beta_{13} = \alpha_{23} = \beta_{23} = \alpha_{31} = \beta_{31} = 0.$$

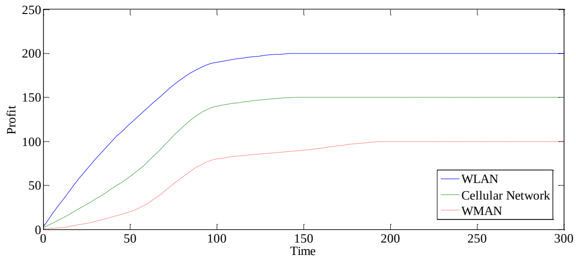
We observe that the large natural growth rate cannot increase the profit of the network but can make the network use less time to achieve the equilibrium point, that is, (200, 150, 100).



(a) $r_1 = r_2 = r_3 = 0.05$.



(b) $r_1 = 0.02$, $r_2 = 0.04$, $r_3 = 0.08$.



(c) $r_1 = 0.08$, $r_2 = 0.04$, $r_3 = 0.01$.

Fig. 4. Profit evolving curves with time.

Then, we compare the profit of each network in cooperative spectrum sharing scheme with the maximum profit of each network in non-cooperative scheme. **Fig. 5** shows the profit evolving curves for WLAN, cellular network and WMAN with time, where $m_1 = 200$,

$m_2 = 150$ and $m_3 = 100$, $r_1 = r_2 = r_3 = 0.01$, $\alpha_{12} = 0.1$, $\alpha_{13} = 0.2$, $\alpha_{21} = 0.3$, $\alpha_{23} = 0.4$, $\alpha_{31} = 0.5$, $\alpha_{32} = 0.6$, $\beta_{12} = 0.3$, $\beta_{13} = 0.4$, $\beta_{21} = 0.5$, $\beta_{23} = 0.6$, $\beta_{31} = 0.7$ and $\beta_{32} = 0.8$. It is seen from **Fig. 5**. that when the cooperative coefficient is larger than the competitive coefficient, the system can reach the equilibrium point, (249.89, 188.49, 124.95), and it is also a stable equilibrium point.

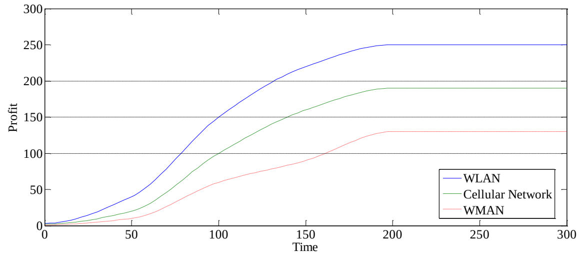


Fig. 5. Profit evolving curves with time.

Fig. 6 shows the profit evolving curves for WLAN, cellular network and WMAN with time, when the cooperative coefficient is less than the competitive coefficient, namely, $m_1 = 200$, $m_2 = 150$ and $m_3 = 100$, $r_1 = r_2 = r_3 = 0.01$, $\alpha_{12} = 0.3$, $\alpha_{13} = 0.4$, $\alpha_{21} = 0.5$, $\alpha_{23} = 0.6$, $\alpha_{31} = 0.7$, $\alpha_{32} = 0.8$, $\beta_{12} = 0.1$, $\beta_{13} = 0.2$, $\beta_{21} = 0.3$, $\beta_{23} = 0.4$, $\beta_{31} = 0.5$ and $\beta_{32} = 0.6$.It is seen that in this case, each network's profit will decrease. Therefore, the excessive competition will decrease each network's profit and make the system unstable.

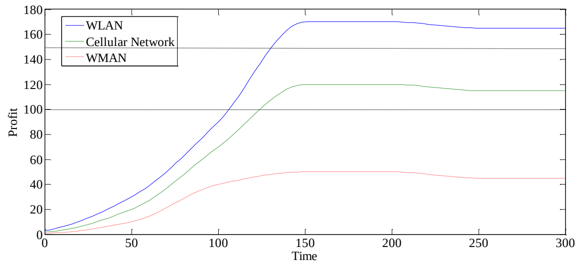


Fig. 6. Profit evolving curves with time.

From the above simulation results, we also can know that when the network system approaches the evolving stable state, the profit of each network in a cooperative scheme is larger than that of each network in a non-cooperative scheme. Therefore, the cooperation of the heterogeneous networks optimizes the system architecture and increases the total profit.

6. Conclusion

As an integral part of the whole, the heterogeneous networks may either compete or cooperate with each other for maximizing the profit. In this paper, we firstly introduce the healthcare monitor network architecture. Then, in this architecture, we analyze the natural growth rate of the network and cooperative and competitive effects among networks. And by the ordinary differential principle, we investigate the stability and its equilibrium points. Finally, analysis and simulation results show that the stability of the coalition system depends on the cooperative mechanism of its subsystems. For further study, we will explore some cooperative schemes of the heterogeneous networks in healthcare monitor network to get the maximizing profit with the least amount of time.

References

[1] Niyato D, Hossain E, "A microeconomic model for hierarchical bandwidth sharing in dynamic spectrum access networks," *IEEE Transactions on Computers*, 59(7):865–877, 2010. Article (CrossRef Link)

[2] Minho Jo, Maksymyuk T., Batista R.L., Maciel T.F., de Almeida A.L.F., Klymash M., "A survey of converging solutions for heterogeneous mobile networks," *Wireless Communications, IEEE* , vol.21, no.6, pp.54,62, December 2014. Article (CrossRef Link)

[3] A. D. Jurik, A. C. Weaver, "Remote Medical Monitoring", *Computer*, vol. 41, no. 4, pp. 96-99, April 2008. Article (CrossRef Link)488261

[4] Chiu K-L, Chen Y-S, Hwang R-H, "Seamless session mobility scheme in heterogeneous wireless networks," *International Journal of Communication Systems*, 24(6):789–809, 2011. Article (CrossRef Link)

[5] Krishnaswamy D, "Network economics considerations for incremental data services in heterogeneous wireless wide area networks," *IEEE 72nd Vehicular Technology Conference* September 2010: 1–5. Article (CrossRef Link)

[6] Ma K, Han Q, Chen C, Guan X, "Bandwidth allocation for cooperative relay networks based on Nash bargaining solution," *International Journal of Communication Systems*, 25(8):1044–1058, 2012. Article (CrossRef Link)

[7] Suri, Pushpa R. Rani, Sona, "Bluetooth security-need to increase the efficiency in pairing," *IEEE Southeastcon*, pp. 607-609, April 2008. Article (CrossRef Link)

[8] M.M. Haque, A.-S.K. Pathan, "Securing U-Healthcare Sensor Networks using Public Key Based Scheme," in *Proc. of 10st Int. Conf. Advanced Communication Technology*, pp.1108-1111, 2008. Article (CrossRef Link)

[9] Niyato D, Hossain E, "Market-equilibrium, competitive, and cooperative pricing for spectrum sharing in cognitive radio networks: analysis and comparison," *IEEE Transactions on Wireless Communications*, 7(11):4273–4283, 2008. Article (CrossRef Link)

[10] Zhou L, Wang X, Tu W, Mutean G, Geller B, "Distributed scheduling scheme for video streaming over multi-channel multi-radio multi-hop wireless networks," *IEEE Journal on Selected Areas in Communications*, 28(3):409–419, 2010. Article (CrossRef Link)

[11] Zhou L, Chao H-C, Vasilakos A, "Joint forensics-scheduling strategy for delay-sensitive multimedia applications over heterogeneous networks," *IEEE Journal on Selected Areas in Communications*, 29(7):1358–1367, 2011. Article (CrossRef Link)

[12] Chang H-B, Chen K-C, "Cooperative spectrum sharing economy for heterogeneous wireless networks," in *Proc. of IEEE GLOBECOM Workshops*, 458–463, 2011. Article (CrossRef Link)

[13] Singh C, Sarkar S, Aram A, Kumar A, "Cooperative profit sharing in coalition-based resource allocation in wireless networks," *IEEE/ACM Transactions on Networking*, 20(1):69–83, 2012. Article (CrossRef Link)

[14] Romer DH, "Keynesian macroeconomics without the LM curve," *Journal of Economic Perspectives. American Economic Association*, 14(2):149–169, 2000. Article (CrossRef Link)

[15] Alemdar, H., and Ersoy, C., "Wireless sensor networks for healthcare: A survey," *Computer Networks*, 54, (15), pp. 2688-2710, 2010. Article (CrossRef Link)

[16] Al Ameen, M., Liu, J., and Kwak, K., "Security and privacy issues in wireless sensor networks for healthcare applications," *J. Med. Syst.*, 36, (1), pp. 93-101, 2012. Article (CrossRef Link)

Xiaoshuang Liu received the M.S. degree from Hebei Normal University, Hebei, China, and the Ph.D. degree from Beijing University of Posts and Telecommunications in 2015. She is currently working in Hebei University of Economics and Business, Hebei, China. Her research interests include optimization, wireless sensor network, et al.

Guixia Kang received the M.S. degree from Tianjin University, Tianjin, China, and the Ph.D. degree in electrical engineering from Beijing University of Posts and Telecommunications (BUPT), Beijing. She was a research scientist in the Future Radio Concept Department of Siemens, Munich, Germany. She is currently a Professor with BUPT. Her interests include the research, development and standardization of 3G and beynd 3G (B3G) wireless communications systems as well as wireless sensor networks.

Ningbo Zhang received his Ph. D. degree from the Beijing University of Posts andTelecommunications, China in 2010. After that, he worked in the Huawei Technology as a senior researcher. From 2010 to 2014, he worked for 3GPP and proposed more than 100 contributions. From 2014 to now, he worked in the Beijing University of Posts and Telecommunications. His research interests include M2M communication, D2D communication, advanced channel coding and modulation, cooperative communication and cognitive radio etc.

Yanyan Guo received the Ph.D. degree from Beijing University of Posts and Telecommunications in 2010. Her research interests include wireless communications systems, and cognitive radio technology et al.