Capacity Analysis of Heterogeneous Wireless Networks under SINR Interference Constraints

W. Mansouri[1], K. Mnif[1], F. Zarai[1], M. S. Obaidat[2] and L. Kamoun[1]
[1]LETI laboratory, University of Sfax, Sfax, Tunisia
[2]Computer Science and Software Engineering Department, Monmouth University, West Long Branch, NJ, 07764, U.S.A.

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Abstract: Next Generation Wireless Networks (NGWNs) are expected to be heterogeneous, which integrate different Radio Access Technologies (RATs) such as 3GPP's Long Term Evolution (LTE) and Wireless Local Area Networks (WLANs) where a transmission is supported if the signal-to-interference-plus-noise ratio (SINR) at the receiver is greater than some threshold. In this paper, we analyze the interference in heterogeneous wireless networks and determine the capacity by taking into consideration the class of traffic of each call and considering both intra-network interference and inter-network interference. This analysis allows us to simplify the estimation of capacity under SINR interference constraints in different wireless networks.

1 INTRODUCTION

Wireless networks are rapidly evolving, and are playing an increasing role in the lives of people throughout the world and ever-larger numbers of people are relying on the technology directly or indirectly (Nicopolitidis et al., 2003). Coexistence of heterogeneous wireless networks appears as an important issue in the NGWNs due to the interference from different radio access technologies, which may cause degradation of Quality of Service (QoS). The interworking between different wireless access networks has been a hot research and development area in the past few years (Yongqiang and Weihua, 2008). Heterogeneous wireless interworking refers to the integration and interoperability of wireless networks with different access technologies, which present distinct characteristics in terms of mobility management, security support and Quality of Service (QoS) provisioning (Zarai and al., 2006). Such works studied the effects of interference in wireless networks (Deepti and al., 2011) and in heterogeneous wireless networks like (Kyuho and al., 2011) and (Robert and al., 2012). They develop a model for the composite interference distribution.

In (Christelle et al., 2008), the capacity is presented as the amount of bandwidth that can be divided with equity to each user. In (Piyush and Kumar, 2000), (Jangeun and Mihail, 2003), the capacity is defined as the maximum bandwidth that can be allocated to each user. The study of the capacity may have different goals. For an operator, the aim is to increase the number of users served while ensuring a better quality of service. For a user, ameliorating the capacity is obtaining more amount of bandwidth to increase its end-to-end data rate. In general, capacity planning is to make sure that the resources will be available to meet future demands (Obaidat and Boudriga, 2010). The need to increase system capacity in wireless networks has driven the research in the field over the past years (Deepti et al., 2011), (Ismail, 2011) and (Weng-Chon and Kwang-Cheng, 2011). In (Weng-Chon and Kwang-Cheng, 2011), the authors propose to deploy some more powerful wireless nodes called helping nodes in order to improve the capacity of homogeneous ad hoc networks. The authors, in (Deepti et al., 2011), study the capacity estimation problem using the SINR as a model for interference and propose algorithms to approximate the throughput capacity of wireless network. In this paper, we address the problem of computation of the total capacity in heterogeneous networks and study the interference in such wireless networks and estimate their throughput capacity.

The remainder of this paper is organized as follows. Related work of this research is summarized in Section 2. Section 3 describes our

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contribution for the interference model. In Section 4 we present the capacity analysis in heterogeneous wireless networks. Simulation results are provided in Section 5. Finally, Section 6 concludes the paper and gives suggestions for future works.

2 RELATED WORKS

In (Weiwei and Lianfeng, 2010), the authors propose a method to determine the total capacity in heterogeneous wireless networks. They begin by presenting the system model, which is composed of N RATs with overlapping coverage in a given area, where resources are jointly managed. They define the system capacity as the maximum number of users that can be admitted while satisfying the required QoS constraints. The authors model the heterogeneous system as a multi-dimensional Markov chain. The proposed method takes into consideration the handoff calls when calculating the maximum number of users. The authors consider the loss probability and the average throughput of admitted users as a required QoS level.

Several research works have focused on analyzing the capacity of a given network such as (Abdellatif et al., 2010) and (Ismail, 2011). In (Ismail, 2011), investigating the capacity and fairness of heterogeneous networks with range expansion and inter-cell interference coordination (ICIC) is provided. The proposed method is limited to macrocell and picocell. In (Weng-Chon and Kwang-Cheng, 2011), Pan and Yuguang investigate the capacity of heterogeneous wireless networks with general network settings. They proposed to analyze the throughput capacity of regular and random heterogeneous wireless networks assuming that the helping nodes are regularly placed and uniformly and independently placed respectively.

3 INTERFERENCE MODEL

We use the signal to interference and noise ratio (SINR) model of interference as described in (Deepti et al., 2011). The set of links that can simultaneously communicate successfully is denoted as $E = \{e_i = (u_i, v_i) : i = 1, \ldots, k\}$. For any $e_i \in E$, the interference at receiver v_i due to all other communications is defined as following:

$$I(v_i) = \sum_{e_j=(u_j,v_j)\neq e_i} \frac{P(e_i)}{d(u_j,v_i)^{\alpha}} \quad (1)$$

Where $P(e_i)$, d and α denotes the power level with which node u_i transmits, the Euclidean distance between nodes u_i, v_i and the path-loss exponent, respectively.

3.1 Interference in LTE

In LTE, the overall transmission power is uniformly distributed among the subcarriers allocated to the same user. As defined in (Liying et al., 2011), the transmission power $P_{i,m}$ of each subcarrier for user i is calculated is given by: $P_{i,m} = \frac{P_i}{12\,K_i}$ where P_i is the overall transmission power and K_i is the number of resource block (RB) in the set K_i, which represents the consecutive RBs assigned to user i. Then the signal to interference and noise ratio in the m^th subcarrier corresponding to user i is written as follows:

$$SINR_{i,m} = \frac{P_{i,m}G_{i,m}G(\theta)}{I + P_N} \quad (2)$$

Here, $G_{i,m}$ is the channel gain from user i to its enhanced-NodeB (eNB), $G(\theta)$ is the antenna gain, P_N is the power of Additive White Gaussian Noise (AWGN) and I is the power of interference, which is given by: $I = I_{own} + I_{other}$ where I_{own} is the intra-cell interference power and I_{other} is the inter-cell interference. As defined in (Pan and Yuguang, 2010), $I_{own} = (1-\alpha)P_i$ with $\alpha \in [0,1]$ denotes the average channel multipath orthogonality factor and P_i denotes the intra-cell transmit power. In the case of LTE, $\alpha = 1$ and hence $I_{own} = 0$. In the Orthogonal Frequency Division Multiple Access (OFDMA) systems, such interference is limited to inter-cell interference, as users within a given cell use sub-carriers which are orthogonal to each other (AbdulBasit, 2009).

3.2 Interference in WLAN

There have been many studies about the interference in WLAN (Sandra et al., 2011). They mainly focus on analyzing the effects of interference in those networks by determining the SINR. The SINR received by user i from WLAN access point AP_j is given by (Kemeng et al., 2007):

$$SINR_{APj,i} = \frac{P_{APj}G_{APj,i}}{\sum_{\substack{k\in AP \\ k\neq j}} P_{AP_k}G_{APk,i} + P_N} \quad (3)$$

Where P_{APj} is the transmitting power of AP_j, $G_{APj,i}$ is the channel gain from user i to its AP_j and P_N is the noise power at the receiver.

4 CAPACITY ANALYSIS IN HETEROGENEOUS WIRELESS NETWORKS

In this section, we develop a mathematical expression for the total capacity of wireless heterogeneous networks taking into consideration the SINR interference constraints.

4.1 Architecture Overview

Most of the researchers mainly focus on interworking between WLAN and cellular networks. The well deployed cellular networks and WLANs will both be included along with other wireless access networks such as wireless mesh networks (WMNs), which consist of dedicated nodes called mesh routers that relay the traffic generated by mesh clients over multi-hop paths. In this paper, we consider an interworking of WMNs with WLAN and 4G cellular networks (LTE) as shown in Fig.1.

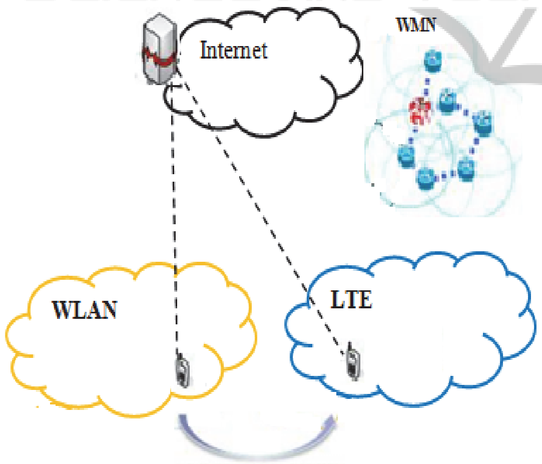

Figure 1: LTE/WLAN/WMN interworking architecture.

4.2 Capacity Analysis

In this section, we evaluate the system capacity of heterogeneous networks by taking into consideration the interference and the type of service. We consider intra-network interference and inter-network interference as proposed in (Tracy, 2003), (Weng-Chon and Kwang-Cheng, 2011). Our architecture is composed of N heterogeneous wireless networks. For a network i, $1 \leq i \leq N$, the total interference consists of intra-network interference and inter-network interference denoted as I^i_{intra} and I^i_{inter}, respectively.

We consider a typical node (reference node located at the origin and it is representative for all other nodes) as defined in (Weng-Chon and Kwang-Cheng, 2011). Let AN_i denote the number of active nodes in the network i. The intra-network interference is given by:

$$I^i_{intra} = \sum_{k=1}^{AN_i} G_k P_i (d^i_k)^{-\alpha} \tag{4}$$

Where G_k is the channel gain from node k to the typical node in the network i, P_i is the transmitting power in the network i, d^i_k is the distance between node k and the typical node in network i and α is the path-loss exponent. The channel gain is modeled by $G_k = s_{ik}(d^i_k)^{-\alpha}$ where s_{ik} is the shadow fading factor with standard deviation values between 6-12 dB (Ayyappan and Dananjayan, 2008) depending on the environment.

The inter-network interference is defined as the total interference caused by the other coexisting networks. For example, the interference I_j caused by network j presents the interference from active nodes in network j to the typical node in network i. Then the total inter-network interference is given by:

$$I^i_{inter} = \sum_{\substack{j=1 \\ j \neq i}}^{N} I_j \tag{5}$$

Where $I_j = \sum_{k=1}^{AN_j} G_k P_j (d^i_k)^{-\alpha}$

Here, G_k is the channel gain from node k to the typical node in the network i, P_j is the transmitting power in the network j, d^i_k is the distance between node k in the network j and the typical node in network i and α is the path-loss exponent.

In this paper, we consider two types of traffic (real time and non real time traffic). Real time (RT) applications such as Voice over Internet Protocol (VoIP) require a limited delay and cannot tolerate a delay higher than this limit. Non real time applications (NRT) are not sensitive to delay and delay variation (jitter) such as data traffic, and e-mail traffic.

We consider a service area covered by multiple networks (RATs). Let R be the set of RATs, $R = \{R_1, R_2, \dots, R_i, \dots R_N\}$. We assume that each RAT R_i $(1 \leq i \leq N)$ has a number of users of class c called $N_c(i)$ where c is the class of service in the RAT R_i, $c = 1,2, \dots, C$ and has a required SINR of class c denoted $SINR_{i,c,req}$. We also consider $SINR_{i,c}(j)$ as the SINR of user j of class c in RAT i. The total number of users in the considered area is denoted as N_u.

Since, the considered area is covered by N heterogeneous wireless networks and each network is transmitting at different power level and has different bandwidth, power consumption, received signal strength and cost, the comparison of SINR of user j in different Radio Access Technologies (RATs) in order to select a candidate RAT is not possible. We propose to compare the ratio of received SINR and the requested SINR. $S_{i,c}(j)$ is defined as follows:

$$S_{i,c}(j) = \frac{SINR_{i,c}(j)}{SINR_{i,c,req}} \tag{6}$$

Where $SINR_{i,c}(j)$ is the SINR of user $j (1 \le j \le N_u)$ of class $c (1 \le c \le C)$ in RAT R_i $(1 \le i \le N)$ and $SINR_{i,c,req}$ represents the required SINR of class c in the RAT R_i. If the term $S_{i,c}(j) \ge 1$, then the received SINR satisfied the requested SINR and then the user can have a communication with the base station or the access point of RAT(i). If $S_{i,c}(j) < 1$ then the user cannot have a communication with this RAT.

In order to determine the capacity of the heterogeneous wireless networks, we begin by calculating the number of users of each class of service connected to each network (RAT). We use the term $S_{i,c}(j)$ to determine the RAT of each user and then calculate the number of users.

For each user, we find out a set r of RATs at which $S_{i,c}(j)$ is maximum as follows:

$$r = \arg\max_{i \in R}(S_{i,c}(j)), \qquad S_{i,c}(j) \ge 1 \tag{7}$$

The set r of RATs can be composed of one or more than one RAT. If $r = \{r_1\}$ then the number of users in the RAT r_1 is given by:

$$N_c(r_1) = N_c(r_1) + 1 \tag{8}$$

Where $N_c(r_1)$ is the number of users of class service c in the RAT r_1. If the set r is composed of more than one element $r = \{r_1, r_2, \dots, r_K\}$ then we propose another criterion for selecting RAT from the set r. In this case the user selects a RAT as the one that is physically nearest to it. We find out the nearest RAT (the distance between the user and the base station or access point) as follows:

$$r_{candidate} = \arg\min_{i \in r}(d_j^i) \tag{9}$$

Here d_j^i is the distance between user j and the base station or the access point of RAT(i) where $i \in r$. The number of users is given by Eq.(8):

$$N_c(r_{candidate}) = N_c(r_{candidate}) + 1$$

As mentioned in (Abdellatif et al., 2010), the bandwidth for the real time calls is calculated as follows:

$$B_{RT} = \frac{E_{RT}/N_0}{W/T_{RT} + E_{RT}/N_0} \tag{10}$$

Where E_{RT} is the energy per bit transmitted for RT calls, N_0 is the density of the white noise and T_{RT} is the transmission rate of RT calls. W is the spread-spectrum bandwidth.

Following the Shannon's formula, the capacity $C_{i,j}$ [in bps] for user j connected to RAT(i) is given by:

$$C_{i,j}(c) = B_{j,c}\log_2\left(1 + \frac{G_j P_i (d_j^i)^{-\alpha}}{I_{intra}^i + I_{inter}^i}\right), \quad 1 \le j \le N_c(i),\ 1 \le c \le C \tag{11}$$

Here, $N_c(i)$ and $B_{j,c}$ are the maximum number of real time (RT) or non real time (NRT) calls of RAT(i) that can be served simultaneously and the bandwidth for calls of class c, respectively. G_j, P_i, d_j^i and α are the channel gain from node j to the base station or access point in the network i, the transmitting power in the network i, the distance between node j and the base station or the access point in the network i and α is the path-loss exponent, respectively.

The sum capacity of all users of class c connected to RAT(i) is given by:

$$C_i(c) = \sum_{k=1}^{N_c(i)} B_{k,c} \log_2\left(1 + \frac{G_k P_i (d_k^i)^{-\alpha}}{I_{intra}^i + I_{inter}^i}\right) \tag{12}$$

Then, the total capacity of all the users in RAT(i) is as follows:

$$C_i = \sum_{c=1}^{C} C_i(c) \tag{13}$$

5 PERFORMANCE EVALUATION

Existing network simulators (NS2, OPNET, etc.) do not provide appropriate support for the simulation of heterogeneous wireless networks with end-to-end communication between nodes using different wireless technologies simultaneously and vertical handovers. In this paper, we use Matlab to implement our own network simulator that allows the modelling of heterogeneous networks at a simplified level.

5.1 Simulation Parameters

We simulate the heterogeneous wireless networks by three networks which have 7, 7, and 6 nodes in WLAN, WMNs and LTE, respectively. The scope of each node in WMN and WLAN is about 50 meters (Philippe, 2010). In this paper, we consider two classes of services (RT and NRT).We assume that the mean arrival rate of new calls follows a Poisson process with parameter λ_1 = 0.12 calls/s (Wei, 2007) for the voice service and λ_2=0.001 calls/s (Kemeng et al., 2007) for the data service.

The simulation parameters are summarized in the following table. Those parameters are selected based on popularly deployed WMNs (Valarmathi and Malmurugan, 2012); (Yin and Liu, 2002), cellular networks (LTE) (Liying and al., 2011), (Jan and al., 2009); (Giuseppe et al., 2010); (Sayandev, 2012) and WLANs (Weiwei and Lianfeng, 2010); (Kemeng et al. 2007); (Tracy, 2003):

Table 1: Main simulation parameters.

		LTE	WMN	WLAN
Bandwidth		10MHz	10MHz	22MHz
Path loss exponent α		3	3	3
Data rate		100 Mbps	2 Mbps	11Mbps
Transmit power		46 dBm	20 dBm	20 dBm
Thermal noise power N_0 (36 PRBs)		-121 dBm per PRB	-96 dBm	-96 dBm
Radius		500 m	50 m	50 m
SINRreq	Voice	-4 dB	12 dB	5.5 dB
	Data	-4 dB	9 dB	5.5 dB
Packet size	Voice	60 bytes		
	Data	1500 bytes		
Movement speed		1 m/s		
Transmission rate for RT calls T_{RT}		12.2 kbps		
Transmission rate for NRT calls T_{NRT}		64 kbps		
Energy per bit transmitted		E_{RT}/N_0 = 4.57 dB, E_{NRT}/N_0 = 4.69 dB		
Handoff deadline		32 ms		
Simulation time		30 minutes		

5.2 Performance Evaluation

In this section, we consider that the size of the heterogeneous network is expressed in terms of the number of users. The users are in an arbitrary topology around the base stations or the access points of the overlapped areas. Figures 2 and 3 plot the results obtained of two different classes of application RT and NRT, respectively. We estimate the capacity of those classes in different RATs where RAT 1, RAT 2 and RAT 3 are LTE, WMN and WLAN, respectively.

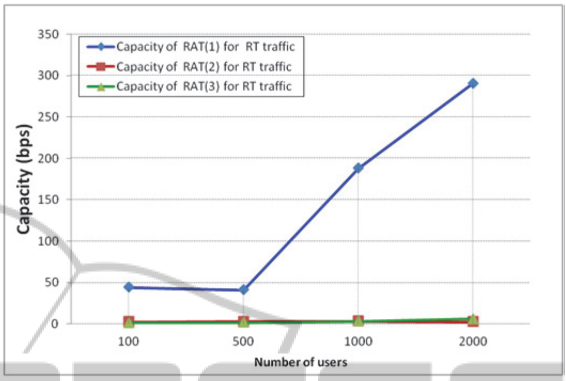

Figure 2: RATs capacity for RT calls.

Fig. 2 shows that the capacities of RT connections vary between 1 and 290 (bps). Comparing the results in Figures 2 and 3, we note that the capacity of NRT traffic is greater than the RT traffics (between 6 and 980 bps). NRT applications are greedy and attempt to inject packets whenever permitted by TCP's congestion window.
In this work, we consider intra-network interference and inter-network interference. The inter-network interference is defined as the total interference caused by the other coexisting networks and the intra-network represents the total interference caused by other nodes transmitting in the same time inside the network.

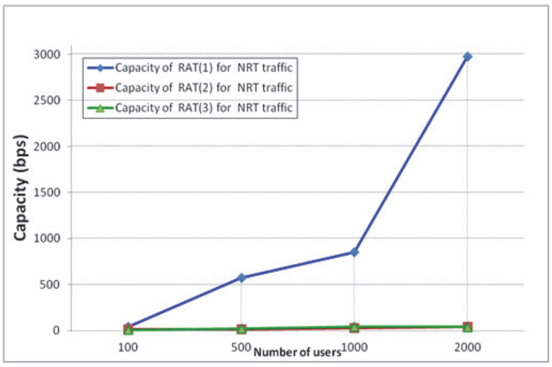

Figure 3: RATs capacity for NRT calls.

When we introduce an interference in the considered area, the power of signals arriving from the base station or the access point of the network will be influenced by the sources of interference that use the same frequency and the SINR value of the considered network will be decreased and then the capacity will be influenced. As a result of the different types of interference, the majority of calls coming on the overlapped areas will be served by the suitable RAT selected by the user according to the proposed SINR ratio among all available ones to make his connection. In Fig. 4, we plot the total capacity versus the number of users with varying the networks. The total capacity of each RAT represents the sum of the real time capacity and the non real time capacity.

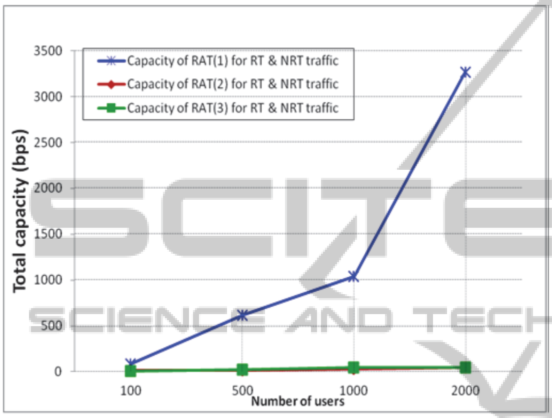

Figure 4: Total Capacity versus number of users.

6 CONCLUSIONS

In this paper, we have estimated the total capacity in heterogeneous wireless networks (LTE, WMNs, and WLANs) in terms of SINR interference constraints. A novel mathematical and simple expression for the total capacity of wireless heterogeneous networks, which considers the intra-network and inter-network interference, is derived. The capacity experienced by a user is dependent on its distance from the access point or base station. It is also dependent on the number of stations in each ring of the RAT. Our strategy takes into consideration both the signal strength and the interference power to select a target network in the integrated wireless environment and then determine the number of users in each in order to estimate the total capacity of the heterogeneous wireless networks. Studying the problem of capacity optimization in the heterogeneous networks would be an interesting extension of this work.

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