International Journal of Soft Computing and Engineering (IJSCE)
ISSN: 2231 – 2307, Volume- 1 Issue- 6, January 2012

Congestion-aware Proactive Vertical Handoff Decision using Coalition Game

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Abstract*—In 4G wireless networks, when a mobile host (MH) with multiple wireless interfaces changes its location or needs a network service, the MH will require a switch between different wireless networks (vertical handoff). Proposed congestion-aware proactive vertical handoff scheme uses coalition game. Its main objective is to decide source and target networks for handoff at minimum congestion in 4G wireless networks. Our mechanism is based on the coalition game formulation. It aims at maximizing the utilization of the resources available and meeting QoS requirement of users as much as possible by initiating vertical handoff. This will reduce congestion level. The performance of proposed scheme is evaluated through numerical analysis.

***Index Terms*— congestion, vertical handoff, Heterogeneous networks, and fairness.**

I. INTRODUCTION

Next generation wireless networks are expected to be heterogeneous consisting of several wireless technologies including, but not limited to, Universal Mobile Telecommunication system (UMTS), General Packet Radio Services (GPRS), and Wireless Local Area Network (WLAN) networks. In 4G wireless networks [1], users of future mobile networks will be able to switch to different radio access technologies. These networks vary widely in service capabilities such as coverage area, bandwidth and error characteristics. As the mobile nodes initiates more applications, the network may have limited resources that would not allow it to provide the same quality of services. This is due to the occurrence of congestion in the network. In order to cope with this constraint, an effective congestion control algorithm is required to deal with such a situation and provide guaranteed radio resources if possible. While motivated by the move towards the integration of heterogeneous wireless networks, the work presented in this paper tries to combine the congestion issue and vertical handoff. The movement of a user within or among different types of networks can be referred as vertical mobility. The paper [2] presents survey report on different types of vertical handoff scheme. The Janise Mcnair et. [3] discuss design and performance issues for vertical handoff in 4G environment. The new Markov decision process [4] with the objective of maximizing the total expected reward per connection designed for vertical handoff decision-making operation. Agent based local and global handoff scheme [5] designed for performing handoff in wireless networks.

All integrated wired and wireless networks in 4G are based on Internet protocol. Transmission control protocol (TCP) has become the dominant communication protocol suite in multimedia applications. Congestion avoidance mechanisms in TCP variants have recently been shown to approximate distributed algorithms that implicitly solve network utility maximization problems. In these algorithms network resources can sometimes be allocated to change link capacities, therefore change TCP dynamics and maximize network utilities. The current approach of congestion control in the Internet is to avoid the development of a bottleneck link by reducing the allowed transmission rates from all the sources. 1) New scheme proposed in [6] called TCP-Jersey, which is capable of distinguishing the wireless packet losses from the congestion packet losses and reacting accordingly. It guides the sender to adjust its transmission rate when the network becomes congested. Congestion control algorithm presented in [7] achieves max-min fair sharing of the available bandwidth in heterogeneous TCP networks.2) A guideline for the congestion control is provided in [8] for improving TCP performance during vertical handover. 3) Design of Finite State Markov Channel model [9] to analyze TCP behavior in wireless network and enhance its performance. 4) New scheme proposed to obtain Global stability [10] in wireless network by putting certain restrictions on the TCP parameters. 5) New scheme [11] to support interactive real-time traffic in 4G networks by estimating media friendliness characteristics of TCP, TFRC, and XCP. 6) Design of Explicit Wireless Congestion Control Protocol (EWCCP) [12] for multihop wireless networks by adding explicit coordination and multibit explicit feedback functionality to TCP protocol. 7) New network layer schemes [13] to increase TCP performance during handoff: Fast ACK, Slow ACK and ACK delaying.

Cross layer approach to congestion control can allocate data rates without requiring precise prior knowledge of the capacity region. In cross layer approach, network jointly optimizes both the data rates of the users and the resource allocation at under lying layer. Cross layer congestion control presented in [14] uses imperfect scheduling information in which number of users in system kept fixed and dynamic. The distributed power control algorithm presented in [15] couple’s power control with existing transmission control protocols. It increases end-to-end throughput and energy efficiency of the network. New cross-layer-approach [16] determines the optimal target network in two phases, i.e. polynomial regression RSS prediction and Markov decision process.

Manuscript received October 09, 2011.

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Increased cell densities, routing layers, and net count all contribute to complex interconnect requirements, which can significantly deteriorate performance and sometimes lead to un-routable solutions. Congestion analysis and optimization must be performed early in the design cycle to improve routability. Related works on congestion estimation are as follows. 1) Net-based stochastic model [17] for computing expected horizontal and vertical track usage, which considers routing blockages due to congestion. 2) Distributed metric model [18] to predict routing congestion and applies it to technology mapping, which is guided by a probabilistic congestion map to identify the congested regions. 3) Effective net-centric model [19] during post processing stage to estimate congestion. 4) Bid based congestion management scheme [20] for a system that accommodates many bilateral transactions by allocating the congestion relief cost. 5) Continuous integration method [21] used to estimate congestion cost. 6) New scheme based on multi-information and fuzzy identification technique [22] to control congestion in wireless mobile Internet. 7) Timing constrained global routing [23] achieved through a network flow formulation to reduce congestion. 8) New congestion control policies [24] for CDMA networks by enhancement to CDMA call admission control and diversity control.

A key design challenge in congestion management is to decide which network should be cooperative to provide service to vertical handoff call and in which cooperative group it will be, especially when the network nodes act in a rational and selfish manner, i.e., in a way to maximize their own performance. Thus solution to congestion control in 4G wireless networks is reduced to coalition formation. Coalition game theory can be used to analyze behavior in decentralized and self-organizing networks. Game theory models the actions and choice of strategies of self-interested players in order to capture the interaction of players in a communication networks. A game consists of

- A set of players N={1,2…n}.
- An indexed set of possible actions $A=A_1 \times A_2 \times A_3 \times \ldots \times A_n$, where Ai is the set of actions of player i (for $0<i\leq n$).
- A set of utility functions, one for each player. The utility function u assigns a numerical value to the elements of the action set A; for actions x, y $\in$ A if $u(x)\geq u(y)$ then x must be at least preferred as y.

In general, game theory is divided into noncooperative and cooperative. Non-cooperative game theory studies the interaction between competing players, where each player chooses its strategy independently and each player's goal is to improve its utility. In contrast, cooperative game considers the benefit of all the players. In coalitional games, players choose the strategies to maximize the utility for all players. In these games, cooperating groups of players are formed, called coalitions. Coalitional games are useful to design fair, robust and efficient cooperation strategies in communication networks.

In a coalitional game (N, u) with N players, the utility of a coalition is determined by a characteristic function u: $2N \rightarrow R$, which applies to coalitions of players. For a coalition $S \subseteq N$, u(S) depends on the members of S. Most coalitional games have transferable utility (TU) viz. utility of a coalition can be distributed between the coalition members according to some notion of fairness. However, for many scenarios rigid restrictions are needed on the distribution of the utility. These games are known as coalitional games with nontransferable utility (NTU). In an NTU game, the payoff for each player in a coalition S depends on the actions selected by the players in S. The core of the coalitional game (N, u) is the set of coalitions that guarantees that no player has an incentive to leave N to form another coalition.

Definition: A collection of coalitions, denoted S, is defined as the set $S=\{S_1 \ldots S_k\}$ of mutually disjoint coalitions $S_i \subset N$. If the collection spans all the players of N that is $\bigcup_{j=1}^{k} S_j = N$, the collection is a partition of N.

Example: Consider a 4G congestion control game (N, u) where N ={WiFi, WiMAX, UMTS}. The players, on their own have no congestion control because vertical handoff will not be initiated. Hence u({WiFi})= u({WiMAX })= u({UMTS}) =0. Any 2-players coalition reduces two thirds of the congestion and hence, u({WiFi, WiMAX })= u({WiFi, UMTS })= u({WiMAX, UMTS})=2/3. The grand coalition reduces the whole congestion and thus u({WiFi, WiMAX ,UMTS}) =1.

In this paper, we investigate the problem of congestion management in a heterogeneous network environment by using cooperative games. Formulating the problem as a cooperative game allows individual networks to cooperate with each other by forming coalitions. Therefore the objective of each network is to maximize the overall objective of the heterogeneous network and try to reduce the congestion in the network. Every member of the coalition manages congestion according its own operation constraints.

The rest of this paper is organized as follows. Section 2 presents the network model. In section 3, our proposed model with coalitional game formulation is designed. Section 4 presents numerical analysis of the proposed algorithm. The paper finally concludes in section 5.

II. NETWORK MODEL

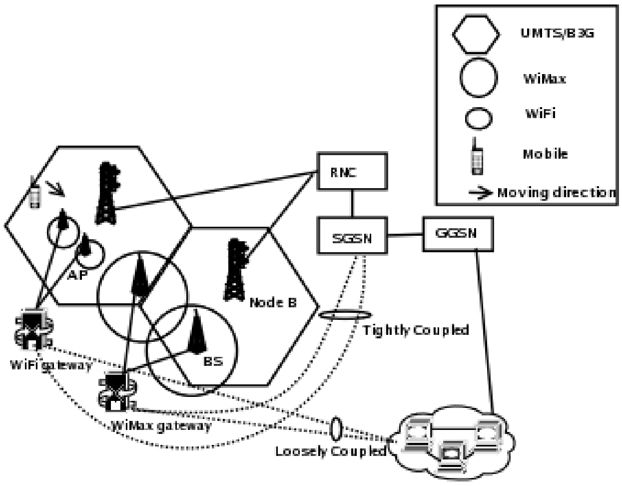

Fig 1: Wireless Network Integrating with WiFi, WiMAX and UMTS

A 4G wireless network presented in figure 1 consists of WCDMA and WiMAX/WiFi networks. These networks are different in network architectures, cell coverage, access control mechanisms, transmission techniques and accessing costs. Table 1 represents features of these wireless networks.

Assume that 4G wireless network includes a single UMTS network, *m* number of Wireless Metropolitan Area networks (WMAN) and *n* number of WLANs. We also assume that the UMTS network covers the entire area, WMAN and WLAN are randomly deployed over the specific areas. Each mobile node supports three interfaces to access WMAN, WLAN and UMTS. A mobile node chooses only one interface for communication at any given time.

Table 1: Comparisons of WiMAX, WiFi and UMTS

Network characteristics	**Wi Fi IEEE 802.11g**	**Wi Fi IEEE802.16**	**UMTS**
Coverage	Small range 100-300 m	Medium range 2-5 km	Large range 3-10km
Bandwidth	High (up to 54 mbps)	Medium (up to 30 mbps)	Low (up to 14.4 mbps)
Billing	Cheap	Medium	Expensive
Security	Weak	Medium	High

There are two integration architectures for providing integrated service capability across 3G and WLAN: tightly coupled architecture and loosely coupled architecture. In the tightly coupled, WLAN appears as another 3G access network and provides 3G services to WLAN users. This architecture utilizes the WLAN gateway to hide the details of WLAN to the 3G-core network. The WLAN gateway is connected to the packet data switch network (PDSN). However in loosely coupled architecture WLAN gateway connects to Internet directly. Loosely coupled architecture completely separates the data paths in 3G and WLAN networks and thus WLAN data traffic do not go through the 3G-core network.

The vertical handoff allows the mobile node to move seamlessly in different wireless network. Also it allows mobile node to transfer connection to different network for managing congestion in the network. Additionally, handoff may be network initiated or MH assisted. In case of network-initiated handoff, the network decides to perform handoff. In case of mobile-node-assisted handoff, mobile nodes provide the RSS to a network controller for making decisions. This research work uses network-initiated handoff. In this case the network initiates the vertical handoff to reduce congestion in the networks. The coalition game is used to decide the source and target networks for vertical handoff.

III. SYSTEM MODEL AND COALITION GAME FORMATION

We consider a group of wireless networks in 4G M= {1,….N} where N is the total number of wireless networks. Source and destination wireless networks needs to be identified to initiate vertical handoff to manage congestion. The solution to congestion management in 4G wireless network is provided using coalition game formation. In this paper the proposed algorithm has been formulated as coalition game with the assumption that all wireless networks in 4G form coalition for minimizing their congestion. The decision coalition formation is formally represented as: $D = [M, \{U_i\},\{P_i\}]$ where M is the number of players, U_i denotes the utility and Pi represents the payoff function. For this game problem, the payoff function is referred to as the Nash equilibrium, which includes each player's best strategy, where other players can choose the equilibrium strategy.

Generally there are 'n' number of wireless networks in 4G with congestion factor Cf_j : j=1,2,3…n. These wireless networks merge together or split to form coalition sets. The merging and splitting of coalition set based on congestion factor. Based on such a parametric definition, the proposed coalition game theory can be described as follows.

Players

Players include i=1, 2, 3 …. n number of wireless networks in 4G networks. These wireless networks cooperate with each other to form coalition sets of networks. Wireless networks in coalition initiate vertical handoff among them to minimize congestion.

Strategy

The strategy of each player is to maximize their payoff. The compensation is defined in terms of minimization of congestion in all wireless networks of 4G by initiating vertical handoff. To improve their performance, the wireless networks can decide to cooperate and form a group. i.e., a coalition S in which the vertical handoff initiated from source to target wireless networks.

Payoff

Payoff reflects the overall performance of the 4G network depending on the coalition formation. The coalition will be the Nash equilibrium with core. In core none of the players, subject to the other player's current strategy, gains any benefit by changing their membership in coalition. The Nash equilibrium with core provides the lowest congestion control by the players. The algorithm is deduced as coalition game theory.

Utility function

It is of the interest for the coalition to take into account the goals: minimization of congestion control and maximization of payoff. Further it is needed to minimize the delays experienced by user data over the multiple networks. An exponential utility function to assign congestion factor (cf) to the networks given as follows.

$$cf_i = e^{d_i / g_i} \tag{1}$$

Where d_i is the packets dropped and g_i is the packets generated for transmission in network i. The congestion factor is computed using the exponential cost function for each network. Based on the congestion factor, networks decide whether to allocate resource or not. We use the congestion factor to optimize network performance. Cost of utility function varies with the congestion factor.

Some wireless networks in 4G have a free bandwidth, whereas other wireless networks experience more congestion. Packets generated from applications can be routed through free bandwidth wireless networks, so that beneficial cost of all the networks increased as well as congestion in the networks get reduced. To decide traffic from which network can be routed by initiating vertical handoff and selection of target network to transfer handoff calls are difficult to realize. We can formulate this problem as a coalitional game. Let us call each congested wireless network as source and every other wireless network in coalition as a target. Assumptions made in this coalition formulation are as follows.

1. Assume that no one wishes to own more congested traffic. Wireless networks in 4G have different congestion factors: denote player i's valuation of congestion factor by cf_i.
2. Assume that there are at least one source and one target in coalition: assume also that some target network congestion factor is less than some source network congestion factor (i.e. for some target i and source j we have $cf_i < cf_j$), so that some vertical handoff of call is mutually desirable and no two players have the same congestion factor ($cf_i \neq cf_j$).
3. Further assume that every wireless network in coalition has free bandwidth to manage the congestion.

Nash equilibrium solution

We define an action of grand coalition to be stable if no coalition can break away and choose an action that all its members prefer. The set of all stable actions of the grand coalition is called the core, defined as follows.

Definition 1: Core of coalitional game: The core of a coalitional game is the set of actions a_N of the grand coalition N such that no coalition has an action that all its members prefer to a_N .

If a coalition S has an action that all its members prefer to some action a_N of the grand coalition, we say that S can improve upon a_N. Thus we may alternatively define the core to be the set of all actions of the grand coalition upon which no coalition can improve. In this coalition game, at the end core is formed with merge-and-split rule. After every period of time t the coalition assessed for possibility of merge and split rule. Thus we have core when no coalition break away to form another coalition. Thus core defines set of actions like initiating vertical handoff among members of the coalitions to improve the utility of the wireless networks. This in turn reduces the congestion in wireless networks.

Coalition Formation Rules and Algorithm

The coalition formation is dynamic process. The members joining to group and leaving from the group occurs periodically. In the initial stage it starts with few numbers of players to form coalition. As time elapses, the collection of coalitions $S=\{S_1,\ldots,S_k\}$ can merge into a larger coalition if merging yields a preferred collection. Similarly, a coalition would split into smaller coalitions if splitting yields a preferred collection. Coalitions will merge only if at least one member of coalition is able to strictly improve its individual utility through this merge (or split) without decreasing the other player's utilities. Thus it is more beneficial to include merge-and-split rules in coalition formation algorithm.

Definition 1: Merge Rule: Merge any set of coalitions $\{S_1, S_2,\ldots S_k\}$ therefore $\{S_1, S_2,\ldots S_k\} \rightarrow \{ \bigcup_{j=1}^{k} S_j \}$(each Sj is a coalition in S).

Definition 2: Split Rule: Split any coalition $\bigcup_{j=1}^{k} S_j$ thus $\{ \bigcup_{j=1}^{k} S_j \} \rightarrow \{S_1, S_2,\ldots S_k\}$ (each S_j is a coalition in S).

We construct a coalition formation algorithm based on merge-and-split technique and have four phases: local congestion sensing, adaptive coalition formation, coalition head and coalition sensing. In the local congestion sensing, each individual wireless networks computes congestion based on the number of packets dropped. In adaptive coalition formation phase, the wireless networks (or existing coalitions of wireless networks) interact in order to assess whether to share their load with nearby networks. For this purpose, an iteration of sequential merge-and-split rules occurs in the network. Each coalition decides to merge (or split) depending on the utility improvement that merging (or splitting) yields. In the final coalition-sensing phase, once the network topology converges following merge-and-split, wireless networks that belong to the same coalition report their utility function (computed using equation 2) value to their local coalition head. The coalition head subsequently uses decision rule to make a final decision. This decision is reported to all the members within their respective coalitions.

Coalitional Game for vertical handoff initiation in 4G wireless networks to reduce congestion

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Initial State

The network is partitioned by $S=\{S_1,\ldots S_k\}$ {At the beginning of all time $T=N=\{1,\ldots n\}$ with non-cooperative wireless networks}.

Four phases in each round of the coalition formation

Phase I – Local congestion sensing

Each individual wireless networks computes its local congestion. Initially coalition consists of individual wireless networks as members in each set.

Phase II – Adaptive coalition formation:

In this phase, coalition formation occurs using merge-and-split.

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Repeat
    S = Merge{S_1,S_2}: coalition sets S1,S2 decide to merge if congestion factor Cf_k k=1,2 of wireless networks are equal with slight variation. This operation executed using the merge rule

    S_1, S_2= Split{S}: coalition in S decides to split if congestion factor Cf_k k=1,2 of wireless networks varies rapidly. This operation executed using the split rule.
until merge-and-split terminates.
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Phase III – Coalition Head

Each member in coalition records the entry time when it enters into coalition. The earliest created member Becomes coalition head.

Phase IV – Coalition Sensing

a) Each member reports its utility function (computed using equation 2) value to its local coalition head.
b) The coalition head of each coalition makes a final decision using function in section III.
c) The members in a coalition abide by the final decision made by the coalition head.

The above phases are repeated throughout the network operation. In phase II, through distributed and periodic merge-and-split decisions, the members can autonomously form the coalition.

Final Stage

Some target network congestion factor in coalition S={ $S_1,S_2\ldots S_k$} is less than some source network congestion factor (i.e. for some target i and source j we have $cf_i < cf_j$), so that some vertical handoff of call is initiated.

Each round of the four phases of the proposed algorithm starts from an initial network partition S= {$S_1,\ldots S_k$} of n. During the adaptive coalition formation phase any random coalition can start with merge process. The coalition Si $\in$ S which has the highest utility in the initial partition S starts the merge by attempting to collaborate with a nearby coalition. On one hand, if merging occurs, new coalition Si is formed, and in its turn, coalitions Si will attempt to merge with a nearby wireless network that can improve its utility. On the other hand, if Si is unable to merge with the early-discovered partner, it tries to find other coalitions that have a mutual benefit in merging. The search ends by a final merged coalition Si final composed of Si . The algorithm is repeated for the remaining Si $\in$ S until all the coalitions have made their merge decisions, resulting in a final partition F. Following the merge process, the coalitions in the resulting partition F are next subject to split operations if possible. An iteration consisting of multiple successive merge-and-split operations i.e. repeated until it terminates.

For handling environmental changes such as mobility or the joining/leaving of mobile nodes, phase II of the proposed algorithm is repeated periodically. In second phase, periodically, wireless networks autonomously manage congestion through new merge-and-split actions with each coalition taking the decision to merge (or split) subject to satisfying the merge (or split) rule. Every period of time t the wireless networks assess the possibility of splitting into smaller coalitions or merging with new partners. For example: Merging of loosely coupled wireless networks yields favorable result to reduce congestion level. Splitting of tightly coupled wireless networks increases packet flow in 4G wireless networks. Similarly after every period of time t in which the current coalition head of a coalition is turned off. The coalition members may select a new coalition head if needed. At the end of the fourth phase the coalition is stable and become core.

IV. PERFORMANCE EVALUATION

We investigate the effect of this Vertical Handoff initiation for Congestion control using Coalition Game (VHCCG) policy. The investigation is performed using a flexible discrete time simulator based on the programming language C that we have developed. It uses fixed time unit framework. Both time and spatial dimensions of the traffic variations are taken into account. Time variation of traffic is represented as arrival process; call duration or packet length for various types of services. In this simulation, one UMTS network, one WiMax network and 28 WiFi network cells with 100m-coverage area serving both packet-switched voice and data calls are considered.

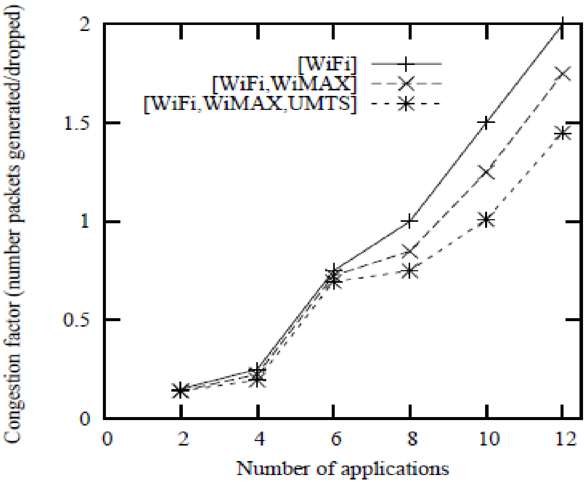

Figure 2: Congestion factor with different coalition

Figure 2 shows the congestion factor of wireless networks in different coalition. We consider three different coalitions for wireless networks of 4G. (i.e., {WiFi}, { WiFi, WiMAX}, { WiFi, WiMAX, UMTS}) in order to investigate the impact of congestion from coordination with other wireless networks. It is observed that WiFi obtains its minimum congestion factor by being a member of different coalitions. For instance, when the congestion occurs the throughput without cooperation is the lowest. Therefore wireless networks find it beneficial to cooperate by forming coalition with other wireless networks.

Further we investigate the effect of this Vertical Handoff initiation for Congestion control using Coalition Game (VHCCG) policy by considering two wireless networks WLAN and UMTS. The traffic generated by each user in the system can be voice over IP. Since we use a discrete time simulator, the new packet-switched calls are generated with Neg. Exponential distributed process either in the WLAN network or in UMTS. It is equivalent to a Poisson process in continuous time simulation, adopted in most of the traffic models. In table 2 we summarize the simulation parameters of the speech traffic.

Table 2: Speech traffic parameters

Voice parameters	Distribution	Mean/value
Inter-arrival calls	Poisson	0-120
Duration of calls	Geometric	120
Max throughput		13

As real time (RT) services are very sensitive to delay, we compare the performance of vertical handoff for congestion control using coalition game (VHCCG) with the Adaptive Hybrid Call Admission Control Policy [25] (A-HCACH). To show the advantages of VHCCG, we evaluate the performance of this algorithm for voice over IP services. In this investigation, the quality measures reported are the delay for processing handoff calls and service time for handoff calls.

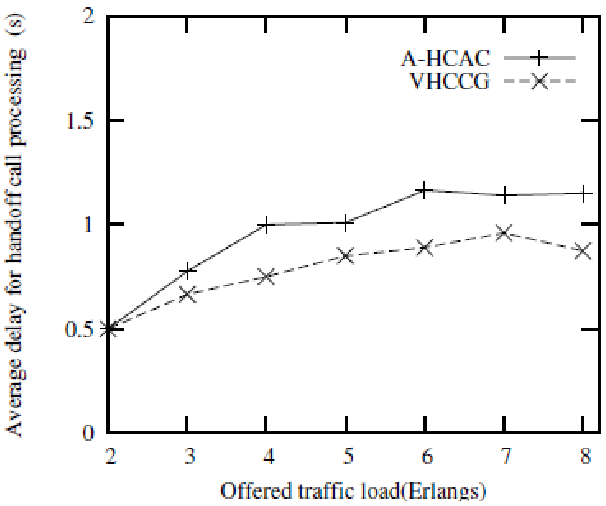

Figure 3: Average delay for handoff call processing

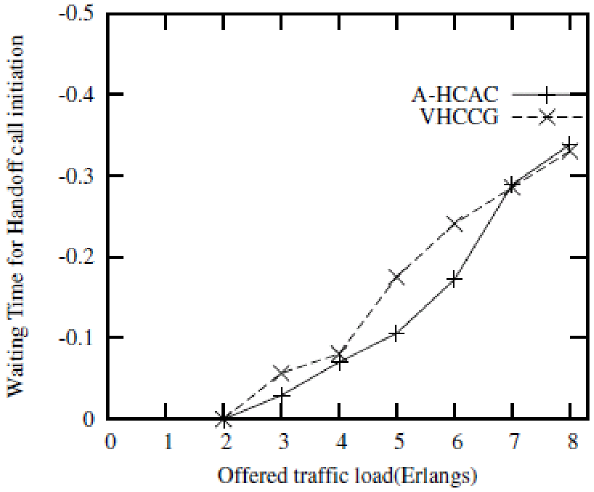

Figure 4: Waiting time for handoff call initiation

In figure 3 we compare the average delay for handoff call processing using schemes A-HCACH and VHCCG. The exhibited results show that the delay for handoff calls is minimum compared to A-HCACH. This is due to balancing of the network traffic by transferring calls to the other system in 4G wireless networks. Figure 4 exhibits the service time for handoff calls in both the scheme. The little gap separates the service time for handoff calls. This gap is due to the fact that during traffic density balancing using VHCCG the handoff call will be served by other system in 4G wireless networks. Hence service time for Handoff call is minimum in case of VHCCG compared to A-HCACH.

V. CONCLUSION

In this paper, we presented a vertical handoff for congestion control using coalition game. Compared with the traditional congestion control algorithms, this congestion control mechanism can manage congestion in the 4G wireless networks by initiating vertical handoff between selected source and target networks. The proposed vertical handoff algorithm considers the design objective of 4G wireless networks. This scheme provides new solution to congestion control by forming coalition game model. And by simulating the proposed vertical handoff algorithm, the VHCCG system shows a less service time and delay for processing handoff calls. The evaluation results prove that the vertical handoff with coalition game can reduce the service time and delay for handoff calls. Future work includes performance analysis of the proposed scheme for real time and non-real time services.

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