Analysis of Required Resources for a Node Using Queue System in an Ad hoc Network

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Abstract— Required resource for nodes in an ad hoc network with specific parameters (e.g. node-count and topology) is one of the most important problems for the manufacturer. In this paper, in the first phase, we showed that according to the proposed game model for the node behaviour, the network converge to a steady state and in the second phase, the process of a node in forwarding the received packets is modeled as a queue system and according to the load of a node the required resources (e.g. buffer-size and average service rate).

Keywords—Game Theory, Queue System, Markov chain, Ad hoc Network, Nash Equlibrium, Resource Analysis.

I. INTRODUCTION

A Mobile Ad hoc network is a decentralized type of wireless network and participation of nodes in packet forwarding is voluntary [1]. The network is Ad hoc because it does not rely on a pre-existing infrastructure, such as routers in wired networks or access points in managed (infrastructure) wireless networks. Because of lacking routers, the network performance becomes highly dependent on collaboration of all member nodes. Outfitting each node with required resources (e.g. the buffer size to store packets, computing power of the processor, required signal strength for connectivity, Power supplier and …) will result in increasing the network lifetime and better performance of the network. Thus, the major question is: how can we calculate the minimum requirements of nodes with a defined condition?

There are two types of MANETs: open and closed [2]. An open MANET comprises of different users, having different goals, sharing their resources to achieve global connectivity, as in civilian applications. This is different from closed MANETs where the nodes are all controlled by a common authority, have the same goals, and work toward the benefit of the group as a whole. In this study we focus on open MANETs. Thus, naturally, nodes tend to use network resources for the sake of the maximum payoffs, and they refuse to consume their limited energy and prevent toprovide forwarding service to others. This selfish and cheating behaviour significantly affects network performance [3]. Therefore, cooperative incentive strategy is in need to efficiently promote the cooperation among nodes. In the following sections it will be proved that according to the proposed game model and the strategy plan of the nodes, the tendency of network nodes to cooperation will converge and the network meets a steady state.

A. *Ad hoc chain*

In this paper we study on Ad hoc network chain which is depicted in Fig. 1. Where M nodes are connected and logically located on a straight line and each node can deliver its packets only to its direct neighbours.

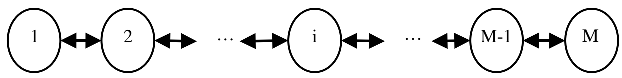

Fig. 1: Topology of Ad hoc network chain with M nodes

The assumptions of network topology are as follows:

(1) Nodes just move in one-dimensional space between their neighbours. The order of nodes does not change. Each node in network has a given power range, and the transmit power of a node is as strength as it could be received by its adjacent node(s);

(2) Transmission between two no-neighbour nodes is based on multi-hop forwarding;

(3) The main reason for the loss of packets in the network is the non-cooperative behaviour of nodes. Limited capacity of nodes is neglected because we assume that nodes have required resources to buffer and forward the packets;

(4) We use a discrete model of time where time is divided into slots. Each node in the network generates some packets. The duration of the time slot is much longer than the time needed to relay a packet from the source to the destination;

(5) The number of packets generated in a node, follows the Poisson distribution with parameter λ. We assume all nodes are similar in packet generation;

(6) Packets generated in a node are sent to all nodes in the network with similar probability. The probability of node j being the destination of a packet generated in node i is $1/(M-1)$ where, M is the number of nodes in the network;

(7) The length of all packets is the same. The cost of sending or forwarding one single packet is *C*, and the payoff of receiving one single packet is *S*;

(8) Nodes can rationally choose whether to forward packets or not. So we use the forwarding tendency ρ to represent the strategy space of nodes;

(9) There is a buffer in each node to store the received packets and forward them one-by-one;

B. Related works

The most familiar approach on game models for network nodes is VCG (Vickrey-Clarke-Grove) route auction model [4], which is mainly aimed at routing game and based on the analysis of one-off game. There are two weaknessesin VCG; the first is that a node may cheat in advertising its cost, and the second weakness is the management of nodes' credits. Because of the credit management, itselfis a difficult problem.In the field of routing strategy an enhanced mechanism for routing is proposed by Omrani and Fallah which uses aprice-based methodfor stimulating cooperation among the nodes of a MANET and their method utilizes the game-theoretic notion of core to distribute the earnings of a cooperation coalition among its members in an optimal manner and they could overcome the selfish behaviour of nodes in their routing strategy [5].

Other than routing approaches, most of works in the field of using the game model in Ad hoc network base on the competition-based behaviour of such network, are focused on topology control [6], [7], [8].The approach proposed in [7] by Komali and his colleagues, uses the potential game theory and best response algorithm to achieve topology control objectives. Komali and his colleagues continued their study and proposed a modified algorithm that accounts the selfish nodes, based on a better response dynamic and showed that this algorithm is guaranteed to converge to energy-efficient and connected topologies [8].

In 2004,DaSilva and Srivastava, proposed a repeated game model and they proved that the nodes cooperate in forwarding of the network packets until their cost of forwarding is not more than their benefit aimed from the network and the Nash Equilibrium is where the cost of forwarding is equal to the node's benefit and violation from this strategy is not profitable [3]. In 2012, Kun Wang and Meng Wu, propose a global punishment-based repeated-game model and investigate the equilibrium conditions of packet forwarding strategies when the whole network is in a cooperative state. Unfortunately they only used the simulation results to approve the network convergence [9].

C. Innovation

Our work resembles to [3] and [9].Our approach proposes a game model so that all nodes in the network achieve a cooperative state. Then in the steady state the required resource of each node such as the buffer size (Number of Packets in Queue) and the computing capability (Minimum Service time) are calculated using Queuing network model and Markov chain concepts.

II. DESIGN OF NETWORK MODEL

A. Repeated Game Model

As mentioned before, we study on Ad hoc chain network which is depicted in Fig. 1, We can assume that each node as a player in a repeated game. In repeated games the game structure is the same in all stages. The payoff of the *i*'th player is:

$$U_i(t) = \sum_{\tau=1}^{t} \delta^{\tau} u_i(\tau) \quad (1)$$

Where $U_i(t)$ is the cumulative payoff in stage *t* for player i, δ is the discount factor and $u_i(\tau)$ is the payoff of user i in stage τ. As the network should work for a long time we consider that the parameter δ is equal to 1.

B. Strategy of a node

The node i cooperates in forwarding packets of other nodes in the network as they cooperate it to correctly deliver its packets to their destinations; Means a node cooperate in forwarding the packets until its payoff is positive.

Definition 1: $\rho_i(t)$determines the tendency of forwarding a received packet in node *i* in stage (time slot) *t*.

Definition 2: $Pr_t(s,d)$ is the probability of correct delivery of packet *(s,d)* in time slot *t*, and in steady state we use only $Pr(s,d)$. If node *s* and node *d* are adjacent $Pr_t(s,d)$ is equal to 1 otherwise:

$$\Pr_t(s,d) = \prod_{k=\min(s,d)+1}^{\max(s,d)-1} \rho_k(t) \quad (2)$$

When the game model is solved, we will obtain the forwarding tendency ρ_i for all nodes in the network. Also $u_i(t)$ in relation (1) is obtained as:

$$u_i(t) = S.\sum_{(s,i)\in R(t)} \Pr_t(s,i) - \rho_i.C.\sum_{\substack{(s,d)\in R(t),\\ (s-i)(d-i)<0}} \Pr_t(s,i) \ , \ S > C \quad (3)$$

The equation(3)has two parts; the first part is interest of node i in using the cooperation of other nodes to deliver its packets to their destinations in time slot *t* and the second part is the trailing cost to node i in forwarding the packets of other nodes in time slot *t*.

C. Node Model

Already suppose all ρ_ks (tendency of forwarding in node k) are presented; and we want to calculate the minimum equipments for a node. A node has the bellow parts:

- Input packets to forward
- Internal generated packets
- Buffer to save Packets
- Processor to Process Packets (Transfer)

We model a node as a M/M/1 Queue as depicted in Fig. 2:

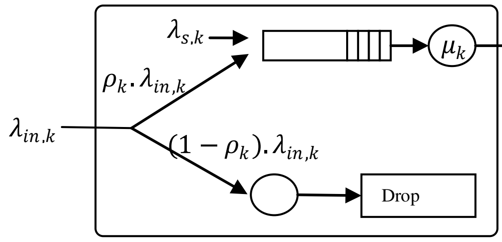

Fig. 2: The queuing model of a node in network chain

- $\lambda_{in,k}$: The rate of arrival traffic to the nodek (assumed it is Poisson distribution);
- $\lambda_{s,k}$: The rate of traffic generation in a nodek (assumed it is Poisson distribution);
- ρ_k: The tendency of cooperation of node k in forwarding an incoming packet (obtained by game model);
- μ_k: The rate of service (transmitting) the packets in node k (assumed it is Poisson distribution);
- λ_k: The rate of input traffic to the processing buffer of node k;

$$\lambda_k = \lambda_{s,k} + \rho_k \lambda_{in,k} \quad (4)$$

The arrival traffic to node k ($\lambda_{in,k}$), consists of two parts, the packets should transfer from a node at left side to the right side of the node k ($\lambda^k_{left\rightarrow right}$) and the packets should transfer from a node at right side to the left side of the node k ($\lambda^k_{right\rightarrow left}$).

$$\lambda_{in,k} = \lambda^k_{left\rightarrow right} + \lambda^k_{right\rightarrow left} \quad (5)$$

We know that each node generates the packets with Poison distribution with parameter $\lambda_{s,i}$ to all nodes in the network. So, the number of packets *(a,b)* in the network follows the Poison distribution with parameter $\lambda_{s,a}/M$. Using the relation (2),$\lambda^k_{left\rightarrow right}$ can be calculated as follow:

$$\lambda^k_{left\rightarrow right} = \sum_{i=1}^{k-1}\sum_{j=k+1}^{M}\frac{\lambda_{s,i}}{M}\Pr(i,k)$$
$$\Rightarrow \lambda^k_{left\rightarrow right} = \sum_{i=1}^{k-1}\frac{\lambda_{s,i}}{M}(M-k)\Pr(i,k) \quad (6)$$

For simplification we assume that the rate ofgeneration of packets in all nodes of the network is equal, so we can write:

$$\forall i \quad \lambda_{s,i} = \lambda_s \Rightarrow \lambda^k_{left\rightarrow right} = \sum_{i=1}^{k-1}\left(\frac{\lambda_s}{M}(M-k)\prod_{j=i+1}^{k-1}\rho_j\right) \quad (7)$$

With similar calculation $\lambda^k_{right\rightarrow left}$ is:

$$\lambda^k_{right\rightarrow left} = \sum_{i=k+1}^{M}\left(\frac{\lambda_s}{M}(k-1)\prod_{j=k+1}^{i-1}\rho_j\right) \quad (8)$$

Thus $\lambda_{in,k}$ is obtained as:

$$\lambda_{in,k} = \sum_{i=1}^{k-1}\left(\frac{\lambda_s}{M}(M-k)\prod_{j=i+1}^{k-1}\rho_j\right) + \sum_{i=k+1}^{M}\left(\frac{\lambda_s}{M}(k-1)\prod_{j=k+1}^{i-1}\rho_j\right) \quad (9)$$

According the relation of M/M/1 queue which is proved in [10], for the steady-state, the probability of existence of n packets in a node which is showed by $P_i(n)$ is:

$$P_i(n) = (1-u_i)u_i^n \quad , \quad u_i = \frac{\lambda_i}{\mu_i} \quad (10)$$

Where, the u_i is the utilization of queue. And the average of packets in a node can be calculated as follow:

$$n_i = \frac{u_i}{1-u_i} \quad (11)$$

III. ANALYSIS OF GAME MODEL

In the following we show that the proposed game model for our network has a Nash Equilibrium.

Initial cooperation tendency $\rho_i(0) = \rho_{max} = 1$ for i=1,2,…,M; where M is the number of nodes in the network. Before the next stage is executed we assume that every node has knowledge about the tendency of cooperation of other nodes $\rho_i(t-1)$. In the nextphase, each node is chosen in a round robin or a random fashion, to determine its "best" cooperation tendency using the **BR algorithm**.

Best Response: The best response (BR) algorithm allows the nodes cooperation tendency to adapt dynamically based on the other nodes' actions. Mathematically speaking, given the cooperation tendency of all other nodes, a node chooses to cooperate at a level that maximizes its utility function according to (12), during each iteration.

$$\hat{\rho}_i = \arg\max_{\rho_i \in [0,1]} u_i(\rho_i, \hat{\rho}_{-i}) \tag{12}$$

We emphasize that as each node evaluates its utility, it considers the best response of other nodes in previous phase. In turn, each node responds to the changes of cooperation tendencies by choosing a tendency that maximizes its utility.

Fig. 3 depicts the algorithmic sequence of the cooperation tendency update mechanism described in equation (12).

Note that in the cooperation tendency update cycle, each time only one node updates its parameter while all others keep their cooperation tendencies fixed.

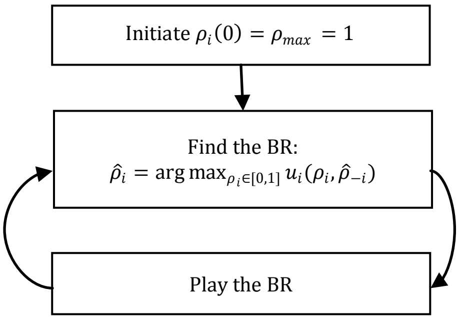

Fig. 3: cooperation tendency update cycle

Now, suppose that node i applies the cooperation tendency $\rho'_i < \hat{\rho}_i$, this strategy will increases the utility of node i for current time slot but for the next stage, all nodes will reduce their cooperation tendency, so this action is not profitable for a node because we assumed that the discount factor δ is equal to 1. Also if the node I uses $\rho'_i > \hat{\rho}_i$, indeed it losses the payoff.

The best response for a node according to the other node cooperation is choosing a cooperation tendency that the payoff of the node in current stage is equal to zero. According to the relation (3) it means that:

$$S.\sum_{(s,i)\in R(t)} \Pr_t(s,i) - \hat{\rho}_i.C.\sum_{\substack{(s,d)\in R(t),\\(s-i)(d-i)<0}} \Pr_t(s,i) = 0$$

$$\Rightarrow \hat{\rho}_i = \frac{S.\sum_{(s,i)\in R(t)} \Pr_t(s,i)}{C.\sum_{\substack{(s,d)\in R(t),\\(s-i)(d-i)<0}} \Pr_t(s,i)} \tag{13}$$

So we can obtain a unique ρ_i for each node.

IV. SIMULATION RESULTS

A. Nash Equilibrium of cooperation tendency

In this section, we present simulation results to demonstrate the validity of our results. In the simulation, a network chain with M nodes and utility function parameters C, S according to different specifications is studied. A node adjusts its cooperation tendencyρ_i that maximizes its utility function in iterations according to (12) until converging.

shows the convergence of the cooperation tendencies (ρ_i) for a network with 15 nodes.

In Fig. 4, R_i stands instead of ρ_i, N_s determines the number of packets generated in each node for current iteration and N_f determines the number of packets that each node cooperates to forward them in current iteration. For example node 1,has 10 generated packets to deliver 10 nodes of the network in iteration 300 and it has no packet for forwarding because of its location at the end of the chain; and node 2 has 14 packets to deliver 14 nodes of the network and 19 packets for forwarding in iteration 300. It is clear that nodes that are located at the middle of the chain have a crucial role in sending packets. Fig. 5 shows the convergence of the cooperation tendencies (ρ) in the network chain with 15 nodes and C=0.3 and S=1.0.

B. Resource Requirements

The goal of our analysis was finding the minimum equipments for nodes to work in special conditions; for example minimum buffer length or minimum service rate with parameter μ for nodes to work correctly in a chain with M nodes that each node generates packets with parameter λ.

In previous section we could find the Nash Equilibrium for cooperation tendencies (ρ_i), according to relations discussed in section II.C, a node is modelled as an M/M/1 Queue.

Suppose a network with 15 nodes (M=15) and the rate of packet generation of k'th node $\lambda_{s,k} = \lambda_s = 11.25$. According to calculated cooperation tendency (ρ_k) in previous section, we can calculate $\lambda_{in,k}$according to relation (9) and λ_k according to relation (4) which is depicted in Table 1.

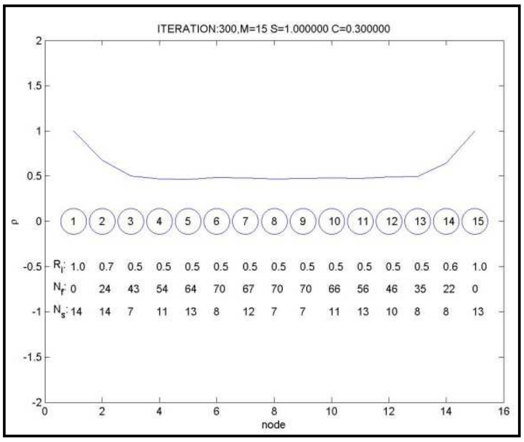

Fig. 4: The converged cooperation tendencies (ρ_I) for a network with 15 nodes

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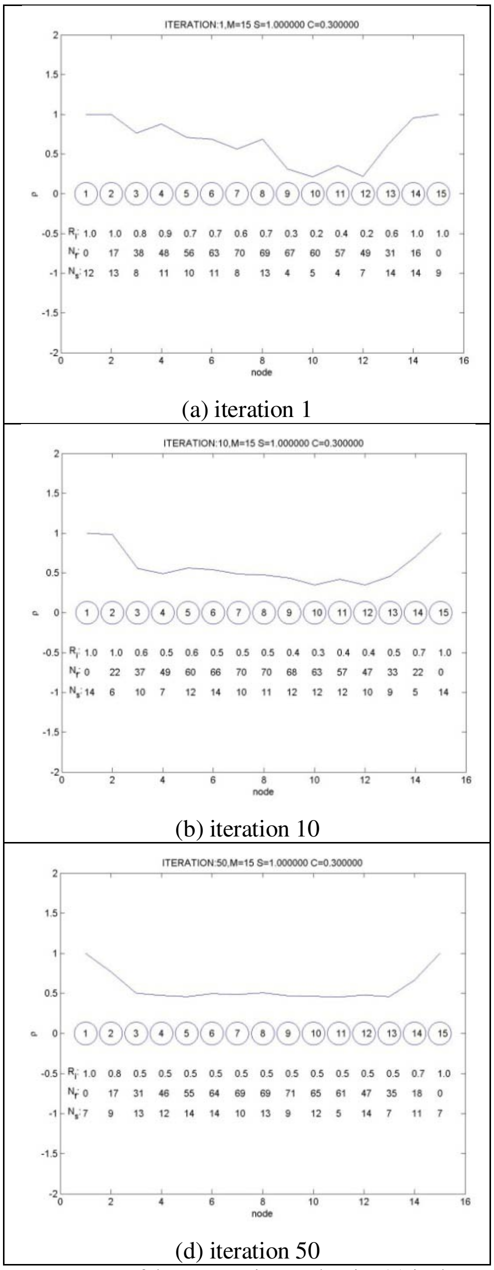

(a) iteration 1

(b) iteration 10

(d) iteration 50

Fig. 5: The convergence of the cooperation tendencies (ρ) in the network with 15 nodes and C=0.3 and S=1.0

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Now, using the relation (10) for different service rates μ, we can calculate u_k for each node. Note that in an industrial product line of devices, all nodes are constructed with similar specifications and it is not affordable to produce devices according to their position in the network chain; thus, in Table 2, the performance of nodes according to different service rates is presented and the service rate of all nodes follows Poisson distribution with parameter μ.The performance of a queue should not be more than 1 why it means the system is unstable, so for [μ]sless than 22, there are some nodes with unacceptable utilities. Generally Table 2, says that for the supposed network with described conditions; at least the service rate of nodes should be more than 22.

Table 1: Calculation of transfering rate in each node according to Nash Equlibrium of cooperation tendency

node	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ρ_k	1.0	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	1.0
$\lambda_{s,k}$	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3
$\lambda_{in,k}$	0.0	11.2	18.0	19.6	19.8	20.0	20.0	19.9	20.2	19.7	19.7	19.3	17.6	11.2	0.0
λ_k	11.3	18.9	20.4	20.5	20.8	20.9	20.9	20.8	20.6	21.1	20.5	20.3	20.1	18.4	11.3

Table 2: Calculation of queue performance u_k for each node according to λ_ks from Table 1 and different service rates μ for nodes

Node→	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
λ_k → / μ ↓	11.3	18.9	20.4	20.5	20.8	20.9	20.9	20.8	20.6	21.1	20.5	20.3	20.1	18.4	11.3
10	1.1	1.9	2.0	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.0	2.0	1.8	1.1
12	0.9	1.6	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.8	1.7	1.7	1.7	1.5	0.9
14	0.8	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.3	0.8
16	0.7	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.2	0.7
18	0.6	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.1	1.2	1.1	1.1	1.1	1.0	0.6
20	0.6	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.0	1.0	1.0	0.9	0.6
22	0.5	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.5
24	0.5	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.5
28	0.4	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.4
32	0.4	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.6	0.7	0.6	0.6	0.6	0.6	0.4
36	0.3	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.3
40	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.3
44	0.3	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.3
48	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.2
50	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.2

Using the relation (11) for different service rates μ, we can calculate the average number of packets in the queue of each node. This parameter is useful to determine the minimum buffer size of nodes. Table 3shows the average queue size in each node of the supposed chain. For example for the service rate of 22 the average queue size of node 10 is 21.11 and for that node and service rate of 50, the average queue size is 0.7.

For a manufacturer, it is important to know the maximum load on its product with different equipments. Table 4, describes the maximum performance and maximum queue size of nodes according to changes of service rate. For example if the manufacturer uses a stronger CPU to increase the service rate (μ), although it can reduce the memory size of the nodes but also it may waste the processing capability because of decrease in u_k according to Table 4.

Table 3: Calculation of the average queue size n_k for each node according to λ_ks from Table 1 and different service rates μ_k for nodes

Node→	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
λ_k → μ ↓	11.3	18.9	20.4	20.5	20.8	20.9	20.9	20.8	20.6	21.1	20.5	20.3	20.1	18.4	11.3
22	1.0	6.1	12.9	13.5	16.6	18.3	18.3	17.5	14.3	23.7	13.9	12.1	10.3	5.1	1.0
24	0.9	3.7	5.7	5.8	6.4	6.6	6.6	6.5	6.0	7.3	5.9	5.5	5.1	3.3	0.9
28	0.7	2.1	2.7	2.7	2.9	2.9	2.9	2.9	2.8	3.1	2.7	2.6	2.5	1.9	0.7
32	0.5	1.4	1.8	1.8	1.8	1.9	1.9	1.9	1.8	1.9	1.8	1.7	1.7	1.4	0.5
36	0.5	1.1	1.3	1.3	1.4	1.4	1.4	1.4	1.3	1.4	1.3	1.3	1.3	1.0	0.5
40	0.4	0.9	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.0	0.9	0.4
44	0.3	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.7	0.3
48	0.3	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.7	0.8	0.7	0.7	0.7	0.6	0.3
50	0.3	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.3

Table 4: Maximum value of u_k and n_k of supposed network for different values of μ

μ	Maximum utility of queue system (u_k)	Maximum queue size (n_k)
22	1.00	23.7
24	0.88	7.3
28	0.75	3.1
32	0.66	1.9
36	0.59	1.4
40	0.53	1.1
44	0.48	0.9
48	0.44	0.8
50	0.42	0.7

The effect of changes of service rate on the performance of nodes and maximum average queue size is depicted in Fig. 6 and Fig. 7.

V. CONCLUSION

For resource requirement analysis, we focused on a special kind of wireless network, named Ad hoc network chain where nodes are logically located on a straight line and each node connects directly to its adjacent node and also all nodes transfer packets to each other using multi hop schema; Then a game model for network behaviour proposed and we showed that that the game converges to a Nash Equilibrium; After that phase, in the Nash Equilibrium state, the load of each node has been calculated and using the queue system model for a node in forwarding the packets the required resources are obtained. The proposed mechanism in modeling the network can be used by manufacturers to produce nodes with required resources. In future work we are going to model an Ad hoc network with mesh topology.

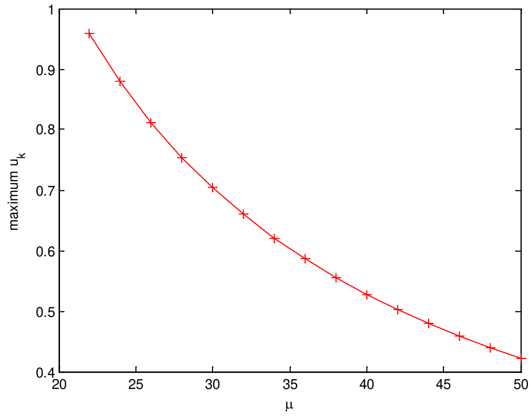

Fig. 6: The effect of increase of service rate μ on Maximum u_k

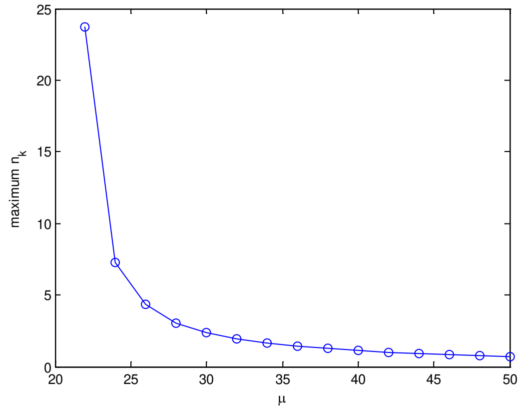

Fig. 7: The effect of increase of service rate μ on required buffer size (Maximum n_k)

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