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Incentive Based Routing Protocol for Mobile Peer to Peer Networks

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Abstract: Incentive models are becoming increasingly popular in Mobile Peer to Peer Networks (M-P2P) as these models entice node participation in return for a virtual currency to combat free riding and to effectively manage constraint resources in the network. Many routing protocols proposed are based on best effort data traffic policy, such as the shortest route selection (hop minimization). Using virtual currency to find a cost effective optimal route from the source to the destination, while considering Quality of Service (QoS) aspects such as bandwidth and service capacity constraints for data delivery, remains a challenging task due to the presence of multiple paths and service providers. Modeling the network as a directed weighted graph and using the cost acquired from the price function as an incentive to pay the intermediate nodes in M-P2P networks to forward data, we develop a Game theoretic approach based on stochastic games to find an optimal route considering QoS aspect. The performance of our routing protocol is evaluated and compared with some existing routing protocols and the result shows that our protocol proves to be efficient compared to shortest-path DSR and multiple paths SMR in terms of average response time, energy and bandwidth utilization in the network.

I. INTRODUCTION

A Mobile Peer to Peer Network (M-P2P) is a dynamic set of co-operating peers communicate by sending messages either through a single hop using a direct wireless link or through multiple hops using a series of wireless links. Wireless links between the communicating nodes can fail and thus, can disconnect two nodes. It can occur when a communicating node leaves the network or move such that they are not in the transmission range of each other. In M-P2P networks, each peer is not only responsible for sending and receiving its own data, but it also has to forward packets from other peers. M-P2P networks have advantages compared to the conventional wireless networks such as rapid deployment, robustness, flexibility and support for mobility, which are useful in a wider range of applications where temporary networks are needed or there is lack of infrastructure. Some of the peers in these networks may be critical from the point of view of survivability. In other words, their failure can cause temporary disruptions in the network either due to their strategic location in the topology or the data they carry. To increase the network life time, nodes with scarce resources such as battery power will demand a high cost to route so that they can provide services for the longer time. A peer could be selfish and save its resources by not cooperating. That is, instead of forwarding the packets to others, a peer could use the resources of others in forwarding only self-originated packets. In battlefield operations, though the nodes naturally co-operate, but at the same time, nodes should drop some of the route requests if those nodes have a high cost to forward a packet. This could

be due to the importance of the node's existence for a longer period which is critical for the successful completion of the mission. Therefore, it has to preserve the energy and forward only selective packets.

Economic models [MMK] play an important role to avoid selfishness and promote co-operation among the peers. Every peer that is a part of the route is rewarded with an incentive (in terms of virtual currency) to forward the packet to the next peer in the route. The protocol discussed in [WCK] focuses on the problem of on demand routing in resource rationed ad hoc networks. This approach shows performance gains in terms of data throughput and energy consumption but it only succeeds in finding a shortest possible route like [BJM] in terms of lowest cost expressed in virtual currency. The protocol described in [WCK] can be categorized as a routing protocol based on best-effort data traffic policy, as it completely relies on finding the best route in terms of cost. Our approach takes into account QoS factors such as available bandwidth, energy used and service capacity, which not only helps in finding a low cost route but also finds a path which has less congestion in the route (more available bandwidth and less workload). As the available bandwidth at a node gives information about traffic condition itself, so using this information helps in finding an optimal route.

By modeling the network as a directed weighted graph and using the cost determined from the price function as an incentive to pay intermediate nodes based on the cost of transmission directly related with the battery usage, we develop a Game theoretic approach based on stochastic games to find the next hop to finally build an optimal cost route. We will also formulate a capacity function which provides QoS support such as bandwidth available, energy used and service capacity in M-P2P networks to forward data. The simulation results show that our proposed Incentive based Routing Protocol (IRP) for single and multiple paths show a better performance in terms of average response time, bandwidth availability and energy utilization in the network compared to the Dynamic Source Routing (DSR) [BJM] for the shortest path and Split Multipath Routing (SMR) [LG].

II. RELATED WORK

Several routing algorithms for M-P2P networks, with their advantages and disadvantages have been proposed in [SGF]. Dynamic Source Routing [DSR] (reactive routing) based on the concept of source routing, Ad Hoc on Demand Distance Vector routing [SGF] (reactive algorithm) where every hop of the route maintains the next hop information by its own and Zone routing protocol [ZRP] which combines proactive and reactive elements are presented. Various incentive mechanisms [CN] have been proposed to promote

selflessness and to foster co-operation in the network. [MMK] discusses economic incentive models and their usefulness for extending existing solutions to entice node participation and handling of resource constraints. Hierarchical Routing [BJM, SGF] in resource rationed ad hoc network has been addressed in [WCK]. Many game theory approaches have been studied in [TS], introducing games such as co-operative games and non-cooperative games. [DLC] proposes a model for resource management in competitive wireless networks, where the interaction between the service provider and the users is modeled as a non co-operative game.

III. MOBILE P2P SYSTEM ARCHITECTURE

Assume that a M-P2P network consists of n peers and each peer communicates in omni-direction and to start with, they all have the same transmission power with a circle of transmission range D . All the links are bi-directional. We model M-P2P network as a directed weighted graph $G=(V, E, w_{ij})$, where V denotes the set of vertices (peers), E the edges (wireless links) on the graph and w_{ij} , the weight on the edge E from v_i to v_j . The link between v_i and v_j exists if and only if these nodes are in the transmission range D . The weight on each edge is defined as the cost of communication from one node to the other. Here, we give some of the definitions used in the system architecture.

Broker nodes (BN): These backbone nodes are the dominant nodes of the virtual backbone network.

Access point nodes (APN): These nodes are the nodes which are at one hop distance from the broker nodes. These nodes act as the access point for all other non back bone nodes in the network to connect to a broker node.

Non Broker nodes (NBN): All nodes other than the broker and access point nodes are the non broker nodes in the network.

Link Failure frequency (LFF): This parameter represents the total number of link failures/ losses of a particular node in a fixed time.

Link Failure frequency System Threshold (LFFth): This parameter represents the system threshold that sets the preferred level of link losses for the backbone nodes.

There are two very important aspects that advocate the use of a broker based system. The first major set of advantages is due to the following facts: 1) Scalability can be achieved when network becomes larger, as every newly joined node connects to the backbone structure 2) Response time for locating services reduces, as every query processes through the broker and these brokers has the current routing information and 3) Servers (peers) are not flooded with the service requests, as every service requests pass through the broker. The second advantage follows from the utilization of the virtual backbones or clusters for improving the efficiency and quality of routing protocols. These two important aspects makes the broker based architecture not only feasible but a preferred architecture for routing in M-P2P networks.

3.1 SYSTEM CONFIGURATION

Backbone network nodes are selected from a subset of the network nodes to form a relatively stable set. It discovers the paths between broker nodes, and adapts to the topology changes by adding/removing nodes into/from the set. Initially, every node is a non back bone (Non Broker) node. Before deciding on their role in the network, these nodes collect their neighborhood information by sending messages, for a time period say T . At the end of the waiting period T and considering the LFF information, any node which satisfies the stability constraint ($LFF < LFFth$) joins the virtual backbone network and identified as the relatively stable node (checking with the link loss threshold ($LFFth$) helps to avoid the nodes with a lot of link losses relative to the backbone nodes). We term the nodes forming the backbone as Broker nodes. The other nodes still keeps on waiting for the messages in the network for the next waiting period T . At any point during the waiting period, if these nodes get messages directly from the Broker nodes, these nodes associates itself with the broker node, hence termed as APN's.(Access Point Nodes). These nodes can join the backbone network based on its LFF information in the next waiting period by satisfying the stability constraint. All nodes other than the BN's or APN's in the network are called as NBN's (Non Broker Nodes). These nodes interact with the broker nodes through the access point nodes which are the direct contact to the Broker nodes. Hence, every NBN has to check for the APN in its transmission range in order to interact with the BN or else find NBN's in its transmission range which has APN in its transmission range. Given any two broker nodes, three kinds of virtual links are possible: 1) Single hop virtual link, where two broker nodes are directly connected i.e. the broker nodes are at a 1-hop distance, 2) 2-hop virtual link, where an APN exists between the two broker nodes. When there exists two APN's between any two broker nodes, they are at a 3-hop distance and hence it is called a 3-hop virtual link. We assume that a maximum of 3-hop distance is possible along the virtual link of two broker nodes when the network is large enough.

Every backbone node keeps the routing information of the BN's in its vicinity or transmission range. If no BN exists in the transmission range it keeps the information of APN's located in its range to communicate with the BN's. Every node (i) that is a service provider has to register with its corresponding BN. If node i want to register its service, it has to register with the BN associated with it, assuming i as a non broker node. If the node i is already a BN, it registers the service at itself. Any time the location of the service provider node changes; it has to register its service with the corresponding BN and unregistering the service at the previous BN.

IV. INCENTIVE BASED ROUTING PROTOCOL

When a source node V_S initiates a request for a data item d stored at a node V_D , all the nodes in the route co-operate in forwarding the data item to the next node to finally deliver the data to the source node V_S . A price p is associated at each intermediate node as the forwarding cost of the data

item d. In the process, each node on the route is paid Virtual Currency (VC) based on a cost function associated for forwarding the packets. Using the virtual currency, available bandwidth and work load at each node, an algorithm using the Game theory is designed to find an optimal route to service the request. To calculate the cost in terms of virtual currency over an edge, we will develop an equation based on various network parameters.

4.1 PARAMETERS AND PRICE FUNCTION

Bandwidth: This parameter indicates how many free bandwidth slots a node possesses for forwarding the data. Each free slot denotes the available bandwidth at a node measured in KB (Kilo Bytes).

Virtual Currency (VC): It is calculated using a price function based on several parameters. Many parameters could be considered, but we confine ourselves to the following:

Transmission Power (P_t): This involves the transmission power (battery power) utilized in forwarding the data packet from the transmitting node to the next immediate node.

Receiving Power (P_r): It is the power involved in receiving a data packet at a particular node.

Euclidean Distance (e): It is the aerial distance between any two nodes in the network. This can be calculated based on the signal strength of the transmitting peer.

Bandwidth (B): This represents the frequency in which these peer's operate.

Elapsed Time (t): It is the time allowed for a mobile peer to respond, after which the peer assumes that the packet is lost. The transmitting peer has to resend the packet or opt for a different route.

Table 4.1: Summary of the notations

Notation	Significance
P_t	Transmission power of a node
P_r	Receiving power of a node
$G_t G_r$	Antenna gains of the transmission and receiving nodes, $G(\text{dB}) \approx 10 \log_{10}(4\pi L_1 \times L_2 / \lambda^2)$
$L_1 \times L_2$	Rectangular area of the antenna aperture in cm ²
λ	Wavelength
e	Euclidean distance
v_w	Constant (the speed of propagation of the wave)
w_{ij}	Weight on an edge
SS	Signal Strength

The total cost incurred on an edge of a shortest path between any two intermediate nodes is defined as

$$w_{ij} = w_{ki} + P_t \left[1 + \left(G_t G_r \left(\frac{v_w}{4\pi e B} \right)^2 \right) \right]$$

According to the Friis Transmission [FTE] equation, the ratio of power received by the receiving antenna P_r to the power input to the transmitting antenna P_t is given by

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi e} \right)^2$$

$\lambda = \frac{v_w}{f} \approx \frac{v_w}{B}$ where for simplicity, we assume that communication is using the same protocol such as 802.11g

and the range of frequency f is proportional to the bandwidth B . Now the above formula reduces to

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{v_w}{4\pi e B} \right)^2$$

We formulate the cost equation into three cases:

(Cost at the source node) At the Source node (data requesting node), the total cost constitutes to only the transmission power of the source node, i.e, $w_{ij} = P_t$ as it does not have a previous node and $w_{ki} = 0$, where i, j, k are the current, next and previous nodes respectively.

(Cost at an intermediate node): At any given intermediate node if P_t is the transmitting power and P_r the receiving power of that node, then the total power used in transmitting and receiving a packet is $T = P_t + P_r$

$$= P_t + P_t \left[\left(G_t G_r \left(\frac{v_w}{4\pi e B} \right)^2 \right) \right]$$

$w_{ij} = w_{ki} + P_t \left[1 + \left(G_t G_r \left(\frac{v_w}{4\pi e B} \right)^2 \right) \right]$ where i, j, k are the current, next and previous nodes respectively

(Cost at the destination node): At the Destination node (data serving node), the total cost constitutes to only the receiving power of the node i.e.,

$w_{ij} = w_{ki} + P_t \left[\left(G_t G_r \left(\frac{v_w}{4\pi e B} \right)^2 \right) \right]$ where i, j, k are the current, next and previous nodes respectively

If SS is the signal strength then Euclidean distance e can be calculated as $e \propto 1/SS$ and w_{ij} calculated in the equations above is used as the virtual currency cost to forward the packets through the intermediate nodes

4.2 CALCULATION OF TRANSMISSION POWER

We use the signal strength and propagation function to calculate the transmit power of a peer,

i.e $P_t = \gamma(l_i, l_j) = SS$ where $\gamma(l_i, l_j)$ is the propagation function defined over $L \times L \rightarrow Z(\text{cm}^2)$, L is the set of locations of the peers over a plane and $\gamma(l_i, l_j)$ gives the loss in bandwidth B due to propagation at location $l_j \in L$, when a packet is originated from location $l_i \in L$. Let the distance between l_i and l_j be e and e_{th} be the threshold distance then γ can be defined as

$$\gamma(e) = \gamma(e_{th}), \text{ if } e < e_{th}$$

$$\gamma(e) = \gamma(e_{th}) + 10 \cdot \epsilon \cdot \log_{10}(e/e_{th}), \text{ if } e \geq e_{th}$$

The value of ϵ is usually between 1 and 5 depending on the environment. Hence, the transmission power is defined as $P_t = SS + \gamma(l_i, l_j)$

4.3 INCENTIVE BASED ROUTING PROTOCOL USING GAME THEORY

All the nodes in the network are the players of the game. Based on each other's decision making behavior, a policy or strategy is developed which helps in finding the best possible route. We fix our outcome as finding the destination peer and look forward to end the game with that desired outcome. The preferences of a peer can be expressed with a utility function, which maps every consequence to a real number. When a peer makes a decision, it chooses one peer over the other, which is defined as the action of the

peer. Sometimes these actions can be defined as the probabilistic distribution which is dependent on the game's behavior, whether it provides the complete information or not. The set of all actions taken by a peer to reach a possible outcome can be defined as a strategy. At the beginning of each stage, the game is in some state and the peers select their actions. Each peer receives a payoff (virtual currency) that depends on the current state and the chosen actions. The game then moves to a new random state whose distribution depends on the previous state and the actions chosen by the peer. The procedure is repeated at each new state and the game continues for a finite number of stages until it reaches a termination stage and an optimal route is found.

To formulate the game in the M-P2P scenario, we consider a discrete time stochastic process, Markov Decision Process (MDP) characterized by a set of states. Each state defines the state of the mobile peer. For each state there are several actions from which decision maker must choose. Any action on a state, results in the change of state for the peer. For a game in any state in S , the application of Action A , will result in a new state $s' \in S$. This is determined by a transition function $P(s)$ which is based on the transition probabilities. Formally, MDP is defined as,

- I. A finite state space $S = \{x_1, x_2, \dots, x_n\}$
- II. A finite set of controls $U(x)$ for each state $x_i \in S$
- III. Transition probabilities $P(x_i, u, x_j) \forall u \in U(x_i)$ that are equal to the probability of next state being x_j after applying control u in state x_i .
- IV. A cost $C(x_i, u)$ associated to $u \in U(x_i)$ and $x_i \in S$

Table 4.2: Summary of notations

Notation	Significance
x_i	A state in the finite state space
$\text{Successor}(x_i)$	A successor state of the state x_i
$U(x_i)$	Set of controls for the state x_i
$C(x_i, u)$	Cost associated with the state x_i and the control u , $u \in U(x_i)$ calculated from the virtual currency price function
$B(x, u)$	Available bandwidth of a node in state x_i
π	Strategy or policy, a finite set of sequence of controls
$C_\pi(x_n)$	Cost associated with the policy
$P(x_i, u, x_j)$	Transition probability

As discussed in Section 3, we consider a MP2P network as a directed weighted graph, with a cost assigned to each arc (edge) of the graph. The game is played among the peers with a peer acting either as a source node, intermediate node or a destination node. A peer as a decision maker can be in one of the states $S = \{x_1, x_2, \dots, x_n\}$. We represent each state as the combination of peers from the source to any intermediate or destination peer. For example, we say that the game is in state x_i if the game has traversed through the peers say p_1, p_2 . Then the state x_i is represented as $\{p_1, p_2\}$. So every time a peer is reached, the game is moved to a new state and the state is represented as described above. The problem now reduces to finding a path from a graph with a set of states and cost associated with each transition (from one state to the other). This can be treated

as a stochastic shortest path problem to select a successor state $\text{Successor}(x_j)$ at each state x_j , such that $(x_j, \text{Successor}(x_j))$ is an edge, and the path formed by a sequence of successor states starting at any state x_1 terminates at the destination state x_n and has a length with minimum sum of costs over all paths that start at x_1 and terminate at x_n .

A stochastic shortest path problem is an MDP problem in which the state space $S = \{x_1, x_2, \dots, x_n\}$ is such that x_1 is the starting state and x_n the destination state. Each state is associated with a finite set of controls $U(x_i)$. The system dynamics are controlled by transition probabilities that maps states and controls to states. Every time the player leaves the state, a cost $C(x_i, u)$ is incurred which is associated with u where $u \in U(x_i)$, $x_i \in S$ and the available free bandwidth $B(x_i, u)$ (a QoS factor) is also considered. A strategy or policy π (for a route) is a finite sequence $\mu_0, \mu_1, \dots, \mu_n$ of functions where μ_i maps states to controls, so that the player applies the control $U(k)$ in state x_i . The cost $C_\pi(x_n)$ associated with policy π , when system starts at x_i (initial state) is $C_\pi(x_n) = E\{C(x_k, \mu_k(x_k))\}$ where the expected value E is induced from the probability distribution of transition probabilities for some k . The cost for a policy $C_\pi(x_n)$ is further refined by eliminating the expectation operator.

$C_\pi(x_i) = \sum_{j=1}^N P(x_{i-1}, u, x_j) C(x_i, u)$ where $C(x_i, u)$ is the cost on an edge and $P(x_i, u, x_j)$ is the transition probability, which is based on the virtual currency cost, bandwidth, Service Capacity and the type of node (BN, APN or NBN, based on Link Failure Frequency defined earlier). All these QoS factors are considered in defining the transition probabilities. Initially, we categorize each of these factors into three different levels {low, med, high} depending on their values. We define a probability function for each of these levels and, the combination of all the probabilities with different factors would determine the transition probability. The probability function is defined in terms of the four independent probabilistic functions described below.

$$P(x_1, u, x_2) = P(\text{VC} | x_2) * P(\text{BW} | x_2) * P(\text{WL} | x_2) * P(\text{TY} | x_2)$$

where, $P(\text{VC} | x_2) = P(x_2 \cap \text{VC})/P(x_2)$,
 $P(\text{BW} | x_2) = P(x_2 \cap \text{BW})/P(x_2)$
 $P(\text{WL} | x_2) = P(x_2 \cap \text{WL})/P(x_2)$ and $P(\text{TY} | x_2) = P(x_2 \cap \text{TY})/P(x_2)$.

We define $P(x_2)$ as the probability of reaching a state x_2 among the set of states identified and $P(x_2 \cap \text{VC})$ as the probability of reaching a state x_2 among the set of states identified with a virtual currency VC (VC can be in any of the three levels {low, med, high}). Similarly $P(x_2 \cap \text{BW})$ as the probability of reaching a state x_2 among the set of states identified with a bandwidth BW (BW can be in any of the three levels {low, med, high}), $P(x_2 \cap \text{WL})$ as the probability of reaching a state x_2 among the set of states identified with a workload WL (WL can be in any of the three levels {low, med, high}) and $P(x_2 \cap \text{TY})$ as the probability of reaching a state x_2 among the set of states identified with a node type TY (TY can be in any of the

three levels {BN, APN, NBN}). For example let's consider that the virtual currency is divided into three different levels {low, med, high} with probability of selecting an edge of low cost is 3/6, medium is 2/6 and high is 1/6. As we need to consider an edge of low cost we give a higher probability for the cost being low. Similarly we define the probabilities for all the QoS factors. This can be seen in the table 4 defined below. The node is categorized as BN, APN and NBN as defined in Section 3.1. Using this categorization, we define probabilities for the selection of a node. The probability for selecting a Broker Node (BN) is higher (based on the network architecture, LFF) than that of APN which is higher than NBN. The probabilities for BN, APN and NBN are 4/7, 2/7 and 1/7, respectively.

The transition probability of an edge is defined as the product of the four independent factors listed above. For example selecting an edge which has low cost, medium bandwidth, medium Service Capacity and the node type as BN will have the probability of (3/6)(2/9)(2/8)(4/7) i.e. 1/63. From the Game theory approach defined above, we select an edge which has the highest transition probability over the set of all possible edges. Hence, it is clear that the transition probabilities of selecting an edge with low cost, high bandwidth, low Service Capacity and node type of BN is always higher ((3/6)(6/9)(5/8)(4/7) i.e. 5/21) than that of selecting an edge with high cost, low bandwidth, high Service Capacity and node type NBN is always lower (which is (1/6)(1/9)(1/8)(1/7) i.e. 1/3024).

A situation might arise where the transition probabilities of edges may be equal. In such a scenario, to select an edge, we prioritize the aforementioned QoS factors in the following order, type of node, virtual currency, bandwidth and Service Capacity. A higher priority is given to the node type in order to select the most reliable path, as the type of node is classified in terms of LFF (Link Failure Frequency). It is unlikely that the transition probabilities of all the QoS factors are equal and if such a case arises, selection of any of the edges proves to be fruitful.

There are always one or more policies that are better than or equal to all the others. These are called the optimal policies.

We denote them by π^* . The optimality is achieved when $C_{\pi^*}(x_i) = \min_{u \in U(x_i)} \{C_{\pi}(x_i)\}$ or $C_{\pi^*}(x_i) \ni C_{\pi}(x_i) \leq C_{\pi}(x_i)$ where $i = 1, 2, \dots, n$, for every policy π

$$\Leftrightarrow C_{\pi^*}(x_i) = \min_{u \in U(x_i)} C(x_{i-1}, u) + \sum_{j=1}^{i-1} P(x_j, u, x_i) C_{\pi}(x_j)$$

The capacity/free bandwidth for the policy is calculated based on the available free slots at a node. The bandwidth at a node is divided into slots and each node maintains the slot information of its neighbor by transferring messages. The free bandwidth between any two nodes is denoted by B(XY) where X, Y are the nodes. To calculate the free bandwidth we take into consideration free_slots(X), which gives the available free slots at a node X. If the nodes are at a single hop distance: $B(XZ) = \min(\text{free_slots}(X), \text{free_slots}(Z))$
If the nodes are separated by a multi hop distance:

$B(XYZ)$

$= \min(\min(\text{free_slots}(X), \text{free_slots}(Y)), \text{free_slots}(Z))$

The generalized form is the recursive equation of a minimization function i.e.,

$B(XYT \dots Z) = \min(\min(\min(\text{free_slots}(X), \text{free_slots}(Y)), \text{free_slots}(T)) \dots \text{free_slots}(Z))$.

Table 4.3: Summary of Notations

Notation	Significance
$P(x_1, u, x_2)$	Probability of reaching a state x_2 from state x_1 on control u
$P(\text{VC} x_2)$	Transition probability of the virtual currency to reach a state given a state x_2
$P(\text{BW} x_2)$	Transition probability of the bandwidth to reach a state given a state x_2
$P(\text{WL} x_2)$	Transition probability of the workload to reach a state given a state x_2
$P(\text{TY} x_2)$	Transition probability of node type given a state x_2

Table 4.4: Probabilities of different levels of QoS Factors

Probability	Low	Med	High
VC	3/6	2/6	1/6
Bandwidth	1/9	2/9	6/9
Service Capacity	5/8	2/8	1/8

Service Capacity is also one of the QoS factors which we consider in defining an optimal policy. We define Service Capacity in terms of workload at a node. If a node is processing more number of requests at a given time we consider the Service Capacity to be high and do not prefer to opt that node in the route. The optimal policy is achieved based on the cost, free bandwidth and service capacity i.e. minimum cost, minimum service capacity and maximum free bandwidth.

V. SIMULATION

We built a simulation environment in Java to study the performance by conducting experiments on the Incentive based routing protocol (IRP) described in Section 4 and comparing it to the Shortest Path Dynamic source routing (SP-DSR) [BJM] protocol. The simulation area is approximately 1000 X 600 meters and it can afford a range of 30 to 150 peers in the network. The maximum connection distance between any two peers is 100 m. The queries are randomly generated and it is done at an average of 5 queries per second. The maximum bandwidth between any two peers is 128 kbps and 8 kbps being the minimum. The movement of the nodes is handled by implementing the random way point model (RWP) [BRS]. In RWP, each node moves along a zig zag line from one way point to the other. The random way points are uniformly distributed over the given area and all the nodes tend to converge at the center. RWP chooses a destination and speed for a node randomly and independently, and the node will keep moving at that speed until it reaches that destination. We randomly choose speed which is uniformly distributed in the interval [1, Vmax).

The formation of the node cluster (Broker architecture) is handled by implementing a Connected Dominating Set

(CDS) [LZT+] model. Several algorithms for the CDS formation have been discussed in [BDC], we have used Steiner tree based CDS construction to define Broker nodes in the network. As discussed in Section 3.1 all the nodes connected to these Broker Nodes are the Access Point Nodes and all the other nodes are classified as Non Broker Nodes. The effectiveness of the protocol can be evaluated by performing experiments on the network. The network is divided into clusters of various sizes. Each cluster will have three types of nodes Non Broker Node, Access Point Node and the Broker Node, which acts as the cluster head. A randomly selected node from one of the clusters requests a service in the network and the service is processed using the proposed Game theoretic approach.

Table 5.1: Simulation Parameters

Parameter	Range
Simulation area	1000 X 600 m ²
Number of peers	30 ~ 150
Maximum connection distance	100 m
Bandwidth between peers	8 ~ 128 Kbps
Queries generated per sec	5

5.1 PERFORMANCE EVALUATION

The results are studied to analyze the metrics such as bandwidth usage, response time, average hop count and energy utilization and compare these metrics with those of Dynamic Source Routing (DSR) [BJM] protocol.

5.1.1 Average response time vs. Number of peers

We define response time as the time required to successfully find an optimal route from source to the destination. We perform the experiment by increasing the number of peers in the network from 30 to 150. Figure 1 shows the plot of average response time against the number of peers. We observe that as the number of peers' increases, the performance IRP gets better compared to the shortest path DSR due to the presence of the broker peer architecture that uses less number of nodes in processing a request.

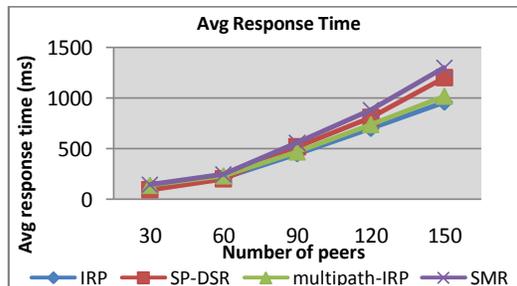


Figure 1: Average response time with increasing number of peers in the network

Initially when the size of the network is small, we see that, both the protocols works equally better. When the size of the network increases, a slight decrease in the response time is observed in our protocol compared to DSR. This is due to the performance of the broker peer architecture, which uses lesser number of peers in processing the request. This experiment shows that the response time in our protocol is decreased compared to DSR. Considering the scenario of

finding multiple maximal disjoint paths to the destination, we observe that IRP for multi paths still performs better compared to split multipath routing (SMR). There is a slight increase in the response time observed compared to IRP for single optimal route as finding maximal disjoint paths costs time over finding all the routes.

5.1.2 Average hop count vs. increasing number of peers

Hop Count is defined as the number of hops a packet takes, starting from the source peer to reach the destination peer. We increase the hop count as the packet reaches each intermediate peer on its way to the destination. Figure 7 shows the comparison between the hop counts by Incentive based routing protocol (IRP) and DSR with the increase of the number of peers in the network.

From the Figure 2, we observe that the average hop count for IRP is little high compared to the DSR. Though not a significant difference is observed, the difference is because of the incorporated QoS factors in finding the route. A slight increase in the average hop count is observed because of the argument that, minimizing the hop-count maximizes the distance traveled by each hop, which is likely to minimize signal strength and maximize the loss ratio.

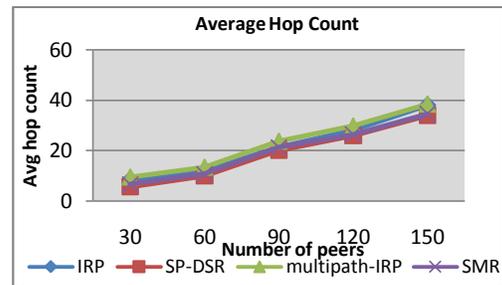


Figure 2: Average Hop Count vs. the number of peers

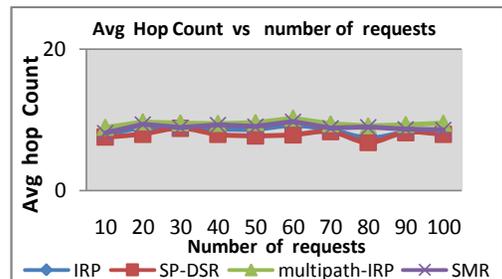


Figure 3: Average Hop Count vs. the number of requests

Even if the best route is a minimum hop-count route, in a dense network there may be many routes of the same minimum length, with widely varying qualities; the arbitrary choice made by most minimum hop-count metrics is not likely to be the best. As IRP selects the route based on the price calculated over several parameters that include signal strength, transmission power and receiving power, and a low cost route is always selected, the route may contain more number of hops with less cost compared to that of DSR which may contain minimum hops with a high cost. When multiple paths are selected in IRP, since more than a single

path is used in routing the packets to the destination, the average hop count in multipath IRP, SMR[LG] increases compared to IRP and SP-DSR.

5.1.2.1 Average Hop Count vs. Number of requests

Figure 3 shows a graph of average hop count plotted against the number of requests in a network. The experiment is conducted over a network of size 60 with the increasing number of requests. The readings are taken for every 10 requests. The irregularity of the graph is due to the randomness in the query generation.

The graph for average hop count for the increasing number of requests shows a slight difference in the hop count as the number of requests increases. Thus, we conclude that increasing the number of requests from 20 to 120 only increase the hopcount by about one and hence, the method scale well with increasing the number of requests.

5.1.2.2 Path Optimality

We define path optimality as the difference between the number of hops a packet took to reach its destination and the length of the shortest path that physically existed through the network when the packet was originated.

Figure 4 shows the scatter graph pointing the differences in the hop count of both the protocols. The readings are taken for a network of size 60 while increasing the number of requests. Each point on the graph shows the difference between the hop counts of IRP and DSR.

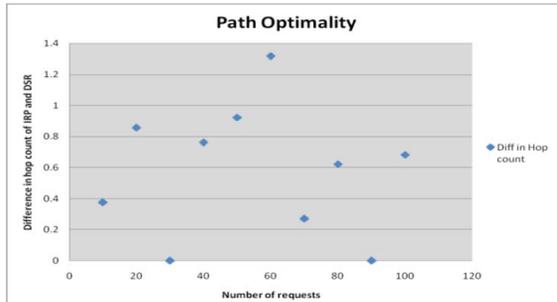


Figure 4: Difference between the number of hops to reach the destination and the length of the shortest path that physically existed (IRP vs DSR).

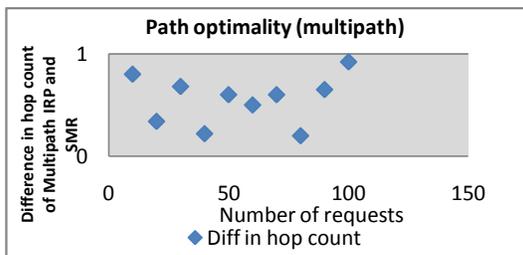


Figure 5: Difference between the average hops in multiple paths and the average length of the shortest paths physically existed (multipath-IRP vs SMR)

Let d denotes the difference between the shortest path and the length of the optimal route actually taken by the packet. A difference of 0 means that the packet has taken a shortest

path while a difference greater than 0 means that it has taken a path longer than the shortest path i.e. it took extra hops to reach the destination. Figure 4 shows the average value of d between IRP and SP-DSR and Figure 5 shows the average value of d between multipath IRP and SMR. We observe that most of the points fall in the range $[0,1]$. This means that the optimal route is close to the shortest path. As the network size is increased we expect a slight increase in the range of d . This plot helps in understanding the ability of the optimal routing protocol to efficiently use the network resources in finding the optimal cost path despite a slight variation in the hop count.

5.1.3 Available Bandwidth vs. Number of requests

We define available bandwidth between any two nodes (or over the path) as the set of available free slots between them. Figure 6 shows the available bandwidth over the path to destination, varying the network of sizes 30, 45 and 60. The readings were taken for 11th, 21st and so on requests. Initially the requests are randomly generated with a difference of 10 queries ranging from 10 to 50 in the network of varying size and the readings for 11th, 21st, and so on requests are taken. The plot shows that initially there is dip in the bandwidth available, this is because of the increase in the number of requests utilizing the bandwidth. However, as more and more requests gets satisfied faster, more bandwidth becomes available to process additional requests. Hence, we observe a rise in the available bandwidth later on with increase in the number of requests.

Figure 7 shows the readings of the available bandwidth for 11th, 21st, so on requests in the network of varying size for multi path IRP. Comparing the graph of figure 7 with that of figure 11, we observe that more bandwidth is available for multi path IRP than that of IRP for single route. This is because of the presence of multiple routes to the destination. Hence, we can infer that multi path IRP performs better compared to the IRP in terms of available bandwidth.

5.1.4 Energy Utilization

Energy utilization is defined as the amount of battery power, transmission power and reception power a node uses in processing a request. As we define our price based on these parameters in VC price function (defined in Section 4.1), we infer that energy utilized in processing a request to be the cost observed along the path. Hence we plot energy in terms of virtual currency derived from the VC price function.

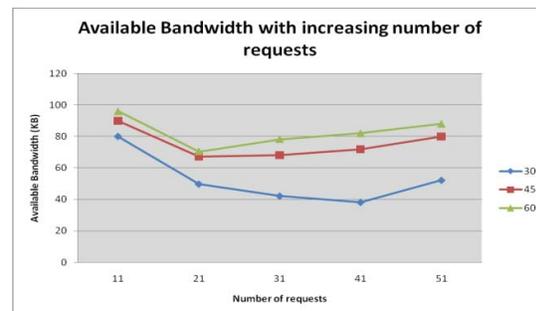


Figure 6: Available Bandwidth vs. the number of requests

Figure 8 shows the graph to read the energy utilized in the network to process a request. The readings are taken by increasing the number of peers in the network ranging 30 to 150. As IRP focuses on finding the low cost path compared to DSR, we observe that the graph of IRP lies below the shortest path DSR. Initially when the network size is small, the difference in the energy is less. But, as the network size is increased we see that IRP performs efficiently in terms of energy utilization as the focus is on finding the low cost route in terms of cost unlike SP-DSR which focuses on finding a path with minimum hops which may cost higher. Considering the multi paths for IRP and SMR, we observe that there is slight increase in the energy utilization compared to the previous models. This is because of the fact that multiple routes are considered from source to the destination. This increases the average cost to the destination, which results in the increase of energy.

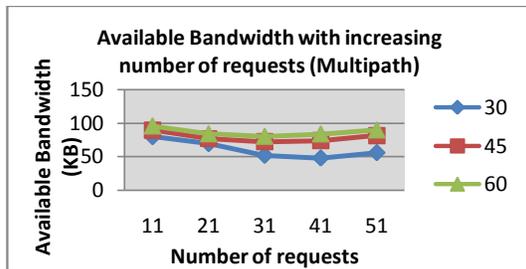


Figure 7: Available bandwidth vs. the number of requests for Multipath IRP

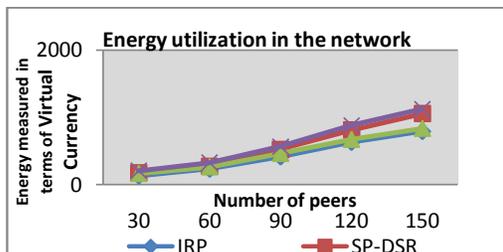


Figure 8: Energy utilization in the network

VI. CONCLUSIONS AND FUTURE WORK

In this paper, we propose a game theory approach for finding an optimal cost routing where each peer gets an incentive to forward the data while discovering a route. In addition, it takes into consideration the QoS factors such as energy usage, the bandwidth available, service capacity, and the link reliability in calculating for the transition probabilities to select the next hop peer in the path. Our simulation study validates that IRP is an effective approach to find an optimal low cost route compared to the shortest path DSR for the average response time, average hop count, path optimality, available bandwidth and energy utilization in the network, and IRP proves to perform better for all the metrics though a slight difference is observed while studying the average hop count.

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