# Incentives Evaluation in 2-hop Relay enabled WiFi Hotspots

Benjamin Bappu, June Tay and Marija Obradovic

*Abstract* — **In this paper we introduce our on-going work on WiFi hotspot throughput optimization using 2-hop relays. We analysis incentives correlations with varying network conditions, node mobility and number of users in the network. Our simulation results provide guidance to optimal network utilization with fair incentive distribution to both users and providers.**

***Keywords*** — **802.11, ad-hoc, incentives, relay, WiFi.**

## I. Introduction

WiFi is a Wireless Local Area Network that enable computers like PDAs and Laptops, and PCs to send and receive data within the range of a wireless Access Point (AP), commonly known as a Hotspot. Generally, hotspots are places where you can have Internet access, for free or for a fee.

Hotspots providers, typically using IEEE 802.11 technology are looking into ways to optimize the network utilization for their service offerings [1]. Though WiFi can offer high bandwidth, the aggregate throughput depends on various factors such as number of connected nodes, interference and range etc. WiFi hotspots generally run in Infrastructure mode (i.e. centrally managed single-hop scheme), where all nodes are connected to and managed by the AP.

In ad-hoc multi-hops schemes, intermediate nodes help relay data, which can improve network performance and extend range. In our two-hop relaying scheme, we proposed a simple and practical 2-hop protocol for Infrastructure mode, where relays are used to improve link throughput [1], [2], [3].

To enable nodes to be relays, we need an incentive framework. This can be easily coordinated in a centralized system. In this paper we focus on the incentive framework, with respect to the number of relays in the network and effect on mobile nodes.

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## II. Handshaking Protocol For Hot-Spots

Our initial design assumes that an AP always transmits at maximum power. Nodes within range can either reply to the AP directly using maximum power or through relaying via intermediate nodes using reduced power. Our approach requires the AP to build a virtual table of nodes corresponding to their signal strength that can be used to determine the appropriate relay node [1]. One of the difficulties here is the location awareness of the nodes. How do we select the best relay such that it is both near the distant node and AP?

Let's say that it takes 100mW (an equivalent of 20dB) to transmit for a distance of 100 metres from AP to node x (PDA) (Fig. 1). In an outdoor wireless link scenario, the coverage distance doubles for every increase of 6dB (9dB for indoors). Similarly, the coverage in RF transmit power is reduced to half for every decrease of 6dB. To transmit from node x to AP takes 100mW. If node r (laptop) is employed to do relaying, node x can therefore reduce its coverage distance (or range) by half. For *outdoor* wireless link condition, node x would take 25mW (14dB) to transmit to node r and with node r taking another 25mW to transmit to AP. In total, it takes 50mW (for indoors its 25mW).

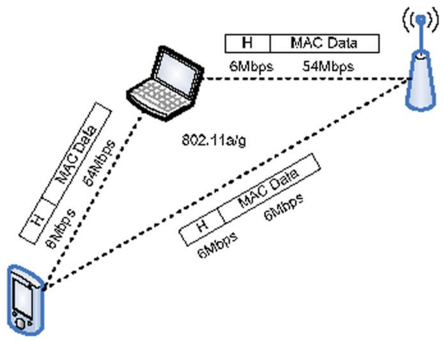


Fig. 1. Two-hop relay in 802.11a/g

Therefore, we can achieve a savings of 50% - 75% in terms of transmit power usage when using relaying excluding overheads such as relay reception power, relay protocol etc. It is possible to achieve a total power consumption for the data throughput between Node x to relay *r* and from relay to AP to be less than the total amount power needed to transmit from Node x to AP directly ($P_{x\to AP} > P_{x\to r} + P_{r\to AP}$). In the best case, we can achieve max upstream rate (R) if both node x and relay use the highest data rate. This also reduces latency. That is, latency (L) at **lower rate** (distant node) is

$L_{x \to AP} = R_{\min\ x \to AP}^{-1}$. Therefore, using a relay with **high rate** can give us a lower latency too. $L_{x \to y \to AP} = R_{\max\ x \to AP}^{-1} + R_{\max\ y \to AP}^{-1}$. For example, in 802.11g (1Mbps to 54Mbps): $L_{x \to AP}$=1 when using low rate, $L_{x \to y \to AP}$=0.037 when using high data rate and hence $R_{x \to y \to AP}$= 27Mbps at high rate gives maximum aggregate throughput (excluding overheads).

Fig. 2 describes a mechanism to identity the *best* relay. For instance, lets assume that node x is associated to the AP using a low transmission modulation rate (at 1Mbps). There are two possible ways to save power using a relay node. One is to use reduced power to transmit to a relay and the other to use the same power, but a high rate (e.g. 54Mbps) via the relay. In the latter case, you save power by reducing transmission time. Most importantly, an appropriate relay needs to be identified. We propose the following technique:

- Node x sends a *relay request* message at full power and low rate. All nodes, including AP will be aware of this request.
- Node x re-sends a *relay request* message at a reduced power (e.g. 50%) and high rate. AP may not be able to receive/decode this message successfully. However, nodes that receive this second message and if they are close to AP, would reply with a *accept request* message at full power. This is to ensure that AP and nearby nodes knows the relay.
- AP will choose the appropriate relay (assuming there is more than one) based on the power tables and policy (such as relay reliability and fair incentive distribution etc).
- Upon confirmation, Node x sends data at reduced power and/or at high rate. Relay node forwards data to AP.
- AP sends ACKs to Node x directly. Note that in this multi-hop scheme, all nodes are always within range of AP's maximum power.

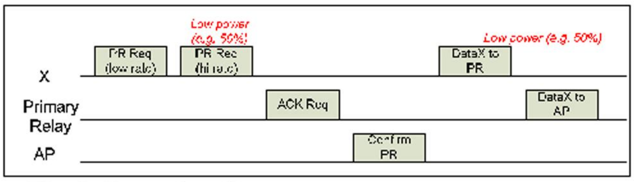


Fig. 2. Best relay discovery

## III. Incentives

In our model, all nodes are registered with a hotspot provider, which simplifies the management of security and incentives for relays.

Nodes that are willing to share power must register with AP, and successfully close the session in order to gain benefits from AP. If a relay node disappears, timeout occurs, and this is followed by a new relay node being appointed by the AP. One way to provide incentives would be to credit a percentage of relayed message data to the relay account, when a successful transaction occurs. The steps include: 1) Potential relay nodes register with AP. This may be done explicitly by the (stationary) user with a click of a button (e.g. a laptop user at a café with abundant battery power). 2) Relay request is being broadcast and relevant relays respond to it. 3) AP selects a suitable relay and starts relay data counter. Relays forward data to AP. 4) Relay session ends with a close request. A percentage of the data counter is credited to the relay's account. We can have different duration and incentives policies set by the AP. A simple incentives policy is described as follows: Assume in a typical hotspot service package, nodes (i.e. customers) are charged on the bytes they transmit and receive. The revenue of the relay enabled network is maximized when its aggregate throughput is higher than the revenue from a non-relay network at a given time interval. A portion of this revenue difference ($\Delta R$) is then given back to the relay nodes ($N$) as incentives. We represent the total incentives as $I_N = (1-\alpha)\Delta R$ where $\alpha$ denotes network operator's additional portion of the revenue. Therefore, for each relay node, incentives can be calculated as shown in Eq. (1).

$$I_i = \frac{R_i \lambda_i}{\sum_{i=1}^{N} (R_i \lambda_i)} (1-\alpha)\Delta R \tag{1}$$

where

$R_i$ is the total number of bytes relayed by node $i$.

$\lambda_i$ is the weight.

The weight can be dependent upon factors such as node rating, demand and mobility. Ratings can be tied to a minimum permissible duration field that ensures registering relays are cost-effective. For instance, any node sharing less than a pre-negotiated amount of time will not get any incentives. This also precludes malicious relay nodes. However, an unintentional disruption (e.g. movement, system crash, severe interference) to relaying may also result in this penalty. A relay rating policy may be used by the AP to rate relays based on their past performance. The number of relays available in the network affects the demand factor and node movement influences the mobility factor, which are discussed further in the next few sections. These factors (or weights) affect the incentives distribution.

## IV. Relay Discovery

As proven in [4], the probability of finding m relays $P_m(R, D)$ is given by Eq. 2, and expected number of relays $E[P_m(R, D)]$ is given by Eq. 3. In A (a cell) there are one source, one destination, and N nodes. The transmission range of the source and the destination are R1 and R2 respectively. The distance between the source and the destination is D.

We assume $\min(R1, R2) < D \le R1 + R2$.

$$P_m(R1,R2,D) = \binom{N}{m}(Z(R1,R2,D)/A)^m(1-Z(R1,R2,D)/A)^{N-m} \qquad (2)$$

$$E[P_m(R1,R2,D)] = \sum_{m=0}^{N} m\binom{N}{m}(Z(R1,R2,D)/A)^m(1-Z(R1,R2,D)/A)^{N-m}$$

$$= N(Z(R1,R2,D)/A) \qquad (3)$$

Fig. 3 shows the behaviour of $E[P_m(R1,R2,D)]$ at fixed power (i.e. 0.06W) when summed from both the source node and the destination node. It is obvious that the relay zone is the largest when there is an identical partition of power between the source node and the destination node. Hence, deriving a higher probability of finding a relay and a bigger number of relays on average.

Fig. 4 presents the behaviour of $P_{m\geq 1}(R1,R2,D)$ at increasing transmit power values of the source node and the destination node. We note that the probability of finding a relay is proportional to transmit power. That is, the probability of finding a relay is much higher when both source and destination transmitter power levels are similar compared to Fig. 3 where power levels vary.

The simulated environment (700×200 m$^2$), using NS-2 [5], consists of one source-destination pair and a given number of nodes uniformly distributed in the area. The distance between source and destination is 200m. The source node is sending data over 802.11b transmission channel at rate 11Mbps. The packet size is set at 1024 Bytes. Traffic sources in the simulation are at constant bit rates. The default Ad hoc On-demand Distance Vector (AODV) routing protocol was used. The number of nodes is gradually increased from 5 to 200 with transmitting power ranging from 0.01W to 0.1W and random background traffic was introduced into the network.

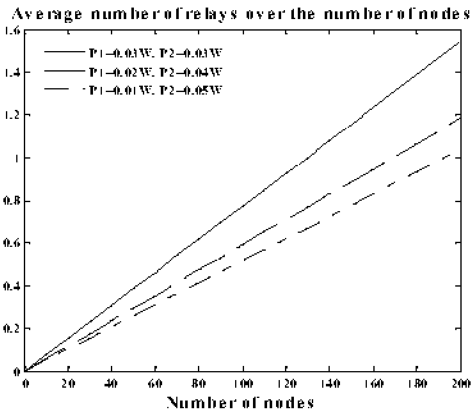


Fig. 3. The average number of relays in function of the number of nodes for different source and destination transmit power levels

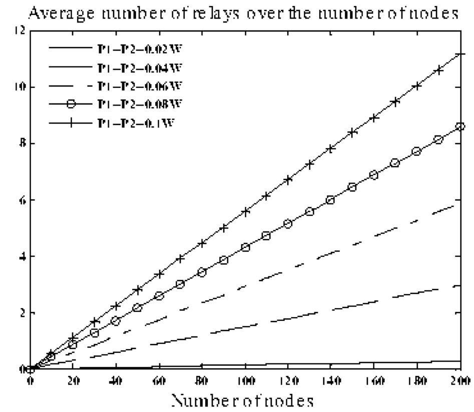


Fig. 4. The average number of relays in function of the number of nodes for different transmit power levels (source and destination having the same transmit power)

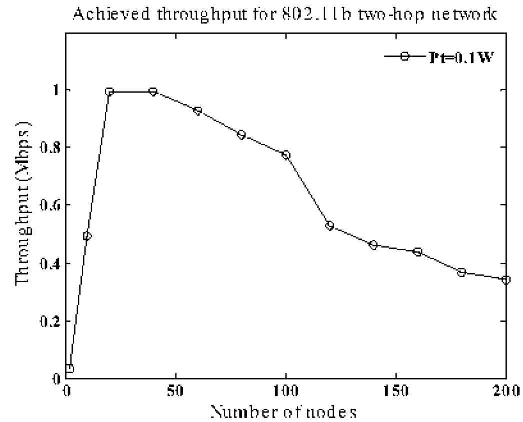


Fig. 5. Throughput for one S-D pair vs. No. of Nodes (with random traffic among nodes in the network)

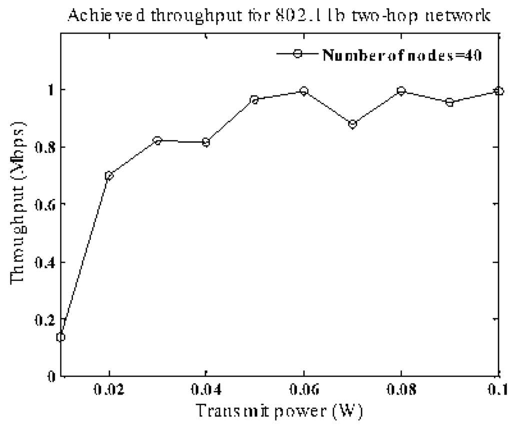


Fig. 6. Throughput for one S-D pair vs. Transmit Power (with random traffic among nodes in the network)

Fig. 5 and 6 shows that there is an increase in the performance of the transmission from the source to the destination with an increase in the number of nodes. However, for a very high number of nodes, the throughput decreases abruptly due to increasing overheads with AODV. We envisage that this would be much less severe if the 2-hop relay protocol was implemented at the MAC layer using infrastructure mode rather than in ad-hoc mode.

Considering the initial results above we conclude that when nodes are "far" and few relays available, AP should increases incentives to motivate nodes to be relays, such that the aggregate network throughput would improve. Conversely, when aggregate throughput starts decreasing abruptly (e.g. increased transmission from nearby nodes) AP should consider decreasing incentives, so as not to penalize the nearby nodes sending at high rates. That is, distant nodes will only benefit from relays if there is sufficient network capacity.

## V. Mobility

In multi-hop WiFi, mobility gives rise to intricate issues for network performance optimization. User mobility results in changes in network topology over time that may cause temporary outages in the multi-hop path. There have been multiple studies on the performance of user mobility, mostly theoretical [6] [7]. These theoretical results show that the performance of the overall network is affected positively by the user mobility but only within a certain speed range. When nodes move at a very high speed, the effects of mobility become very destructive with additional radio-signal impairments like Doppler Effect.

Simulation results in [8] present the throughput, loss rate and delay for a network (having 10, 20 or 40 nodes) with respect to speeds of the node (from 0 to 150m/sec). The nodes in the simulated network move according to the "random way point" model. During simulation, each node randomly selects a destination and moves towards it with a specified speed. On reaching this destination it repeats the above procedure (i.e. selects a new destination) until the end of the simulation. Stationary nodes are modeled by the speed value of zero. Our traffic sources in the simulation were using CBR with AODV as the routing protocol. We then divided the speed range into 4 parts: (1) no mobility (at 0m/sec), (2) low-mid mobility (20m/s), (3) mid-high mobility (20-60m/s) and (4) extremely high mobility (60-150m/s). Though it may seem unrealistic to have mobility in the range of 100m/s which is almost the speed of a commercial plane, we cannot neglect the fact that in the near future there may be many highly mobile devices with high speed connections. At low mobility, throughput is higher whereas at higher mobility, throughput is lower. The fourth group should get the least incentives due to the poor performance obtained.

The performance of the overall network differs depending on the number of nodes in the network (among which the percentage who are mobile). From [8], it is seen that the delay is extremely high (and non linear) when the number of nodes increase from 20 nodes to 40 nodes. We can use the results to give fair incentive distribution. For instance based on Eq. (1), a relay node moving too fast (i.e. negative fluctuations in the received power strength) may be given a lower weight.

## VI. Conclusion

TCP flows are known to perform very poorly over networks with high mobility due to its connection oriented nature. For instance, since packet losses are treated as congestion in the network, TCP algorithms will react to it by backing off sharply, resulting in unnecessary performance loss. Perhaps, incentives should be based on the type of flows. If so, should the node using a TCP flow be charged less, since in the first place, the network has not been that conducive for TCP flows. This is an area of further research.

In this paper we introduced a way of distributing incentives to relay nodes. Our simulation results provide guidance on how incentives should be distributed to the relay nodes depending on how fast they are moving and how many other relays are available in the network.

As future work, we plan to exploit different incentive scenarios for different types of network configurations. We also aim to implement the proposed 2-hop relay scheme at the MAC layer, which will greatly reduce overheads and increase network performance.

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