Throughput Analysis for Slotted Peer-to-Peer Wireless Networks

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Abstract — **An ad hoc network is a collection of wireless nodes forming a network without the use of any existing network infrastructure or centralized coordination. In our work we are considering a regular linear network model, where nodes transmit their information messages over a common radio channel and packets are sent between pairs of nodes in a single-hop fashion. We obtain closed-form expressions for user throughtput as a function of inter-node separation.**

I. Setting

We consider a regular linear network where n nodes are located on a straight line, with separation distance d. The reason for considering regular linear networks is for analytical simplicity. As this model incorporates the distance between nodes, the propagation model is described by means of two effects : the signal attenuation due to the distance r between the transmitter and the receiver, proportional to $r^{-\alpha}$, where α is the power loss exponent (positive number); and Rayleigh fading, which causes the instantaneous envelope of the received signal to be Rayleigh distributed and its power to be an exponentionally distributed random variable. The received power from a mobile at distance r is expressed as

$$P_R = R^2 r^{-\alpha} P_T = \gamma r^{-\alpha} P_T \tag{1}$$

where R is a Rayleigh distributed random variable (with unit power for simplicity) and γ is an exponentially distributed random variable (for simplicity we consider that γ has mean equal to 1).

In the system we are considering, each node can transmit over a common wireless channel. Packets are sent from a node to another in a peer-to-peer single-hop fashion. Apart from the slotted transmission structure where nodes transmit packets within slots of defined duration, nodes are completely uncoordinated. For our analysis we made the following assumptions :

- We suppose single-user decoding where each decoder treats the signals from other users as noise. Moreover the single-user decoder for each node has perfect knowledge of the channel gain.
- For each slot, each node transmits a packet with probability p_t and remains silent with probability $1 - p_t$.
- The system is completely symmetric with respect to any user : all users have the same transmit power, i.e., $P_k = P\ \forall k = 1, \ldots, n$.

II. Results

We define $\Pr[I < R]$ as the outage probability of the channel, indicating the probability that the mutual information I falls below some fixed spectral efficiency R. Expressions of the mutual information necessary for the outage probability evaluation are derived under the assumption that all users signals are Gaussian with flat power spectral density. The gaussian assumption yields an upperbound to the minimum achievable outage probability (see [1]). The Shannon capacity formula for the additive white gaussian noise channel for a transmitter receiver pair is :

$$C_i = \log\left(1 + \frac{\gamma_i P r_i^{-\alpha}}{N_0 + I_n}\right) \text{bits/dim} \tag{2}$$

where the subscript i denotes the intended user, N_0 is the background noise power, P is the transmit power and $r_i = |X_i - X_j|$ where X_j is the position of the receiver and is considered to be 0. I_n is the interference for n possible transmitting users. The outage event is defined as $C_i < R$ and outage probability of intended user i (using (2)) is given by :

$$P_{out}(i) = \Pr\left(\gamma_i < (2^R - 1)\left(\frac{N_0 + I_n}{P r_i^{-\alpha}}\right)\right) \tag{3}$$

As I_n is the sum of independent random variables,we use the properties of the moment generating function to obtain finally :

$$P_{out}(i) = 1 - \exp\left(-\frac{(2^R - 1)N_0}{P r_i^{-\alpha}}\right) \prod_{\substack{k=1 \\ k \neq i}}^{n} \frac{p_t}{1 + (2^R - 1)\frac{r_i^{\alpha}}{r_k^{\alpha}}} + 1 - p_t \tag{4}$$

The throughput for the intended user (as defined in [2]) is given by :

$$\eta(i) = R p_t (1 - P_{out}(i)) \qquad \text{bits/dim} \tag{5}$$

The optimal throughput w.r.t rate and transmit probability as a function of SNR is obtained numerically.

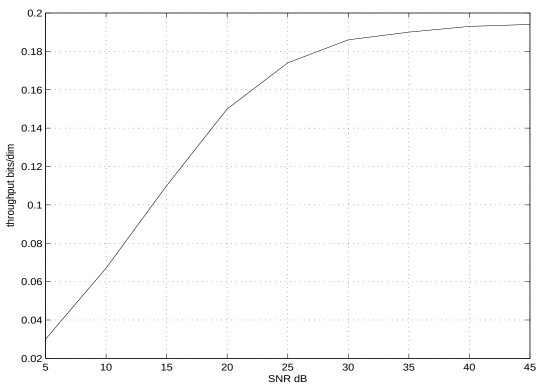

Fig. 1: Optimal throughput versus SNR, n=30 nodes, intended user is in third position $X_i = 3$.

References

[1] G.Caire et al, “System Capacity of F-TDMA Cellular Systems”, *IEEE Trans. on Commun.*,Vol.46, No.12, pp.1649 – 1661, Dec. 1998.

[2] Daniela Tuninetti, “Multi-user Information Theory for Block-Fading Wireless Channels”, *PhD Thesis*, ENST 2002.