A QUEUING MODEL-BASED INCENTIVE SCHEME FOR OPTIMAL DATA TRANSMISSION IN WIRELESS NETWORKS WITH SELFISH NODES

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OUTLINE

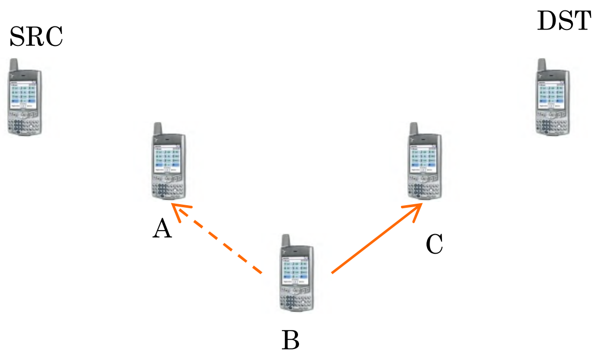
- Introduction
- Credit-based Queuing Analysis Approach
- Network Simulation
- Conclusion

INTRODUCTION

- Self-organized multi-hop networks depends on the cooperation among nodes for transmission.
- Two Type of uncooperative nodes:
  - Malicious Nodes
  - Selfish Nodes
- Stimulation approaches:
  - Reputation-based mechanism
  - Credit-based mechanism

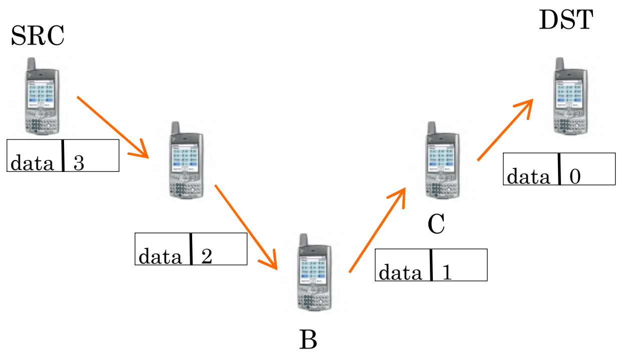
INTRODUCTION

Reputation-based



- Rely on neighbor monitoring to evaluate the reputation of neighbor nodes and excluding nodes with low reputation
- Watchdog: Keeps track of the reputation of neighbor nodes
- Path rater: Avoids routing through nodes with low reputation

Credit-based



- Virtual currency, nuglet, is used to encourage cooperation
- Each packet is loaded with nuglets by the source node
- Each relay node charges a nuglet from the packet before forwarding it

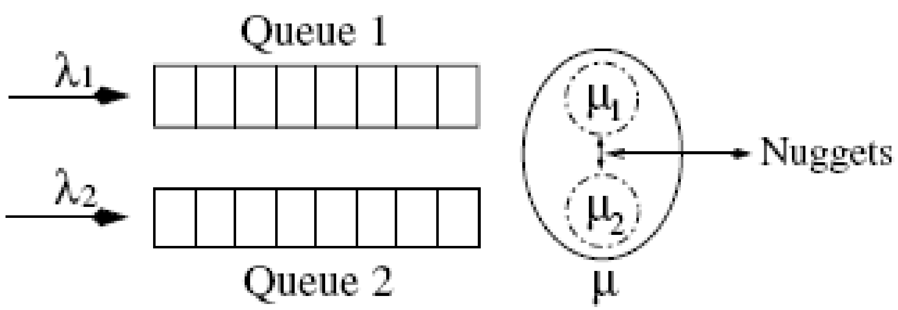
INTRODUCTION

- Cooperation stimulation problem can be interpreted as a resource allocation problem if nodes are assumed to be selfish and rational.
  - Selfish node tends to utilize all of its resource (BW, Power etc), to maximize its benefit
  - Although each node is only interested in transmitting its own data, part of its resource, bandwidth, has to traded in order to establish a routing path
- An incentive scheme is proposed to encourage cooperation based on credit-based queuing analysis approach

CREDIT-BASED QUEUING ANALYSIS APPROACH

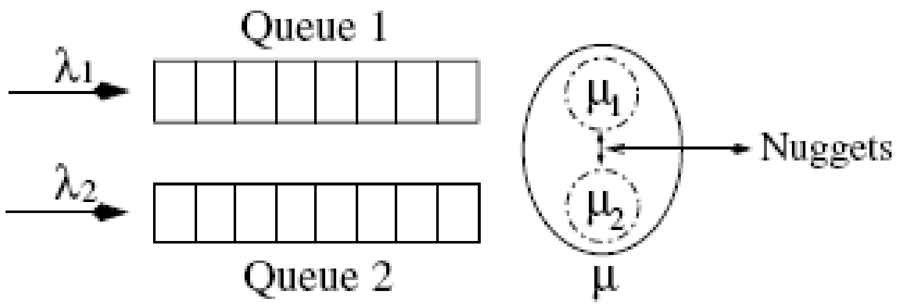
- Queuing model considers bandwidth constraint
- Bandwidth is shared between self generated traffic and relay traffic
- Based on queuing model, selfish node identifies best strategy to allocate bandwidth resource and minimize own packets' drop rate

NODAL MODEL



- Each node has initial number of nuggets: C.
- When node wants to send its own packet, it loses N nuggets by loading the packet with nuggets.
- Each intermediate node earns one nugget when it helps the source node forward a packet.
- Each node maintains two queues:
  - Queue 1 for data packets from neighbors
  - Queue 2 for self generated packets

NODAL MODEL



- λ_1 , λ_2 denote the average arrival rates for queue 1 and queue 2
- μ_1 , μ_2 denote the service rates for queue 1 and queue 2
- $\mu_1 + \mu_2 = \mu$, u depends on the available bandwidth.
- μ_1 indicates the degree of cooperativity.
- Objective: optimize bandwidth allocation to minimize drop rate of own packets.

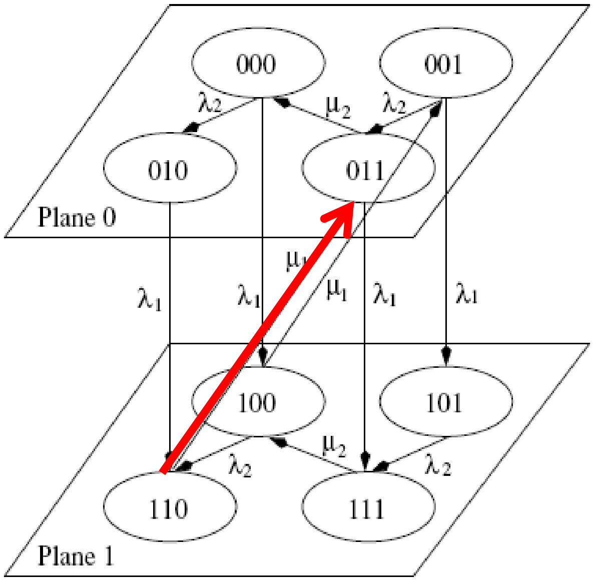
STUDY OF A SIMPLE CASE

- C=M_1=M_2=N=1 (M_1, M_2 are maximum queue lengths)
- State x(i,j,k) indicates there is i packets in queue 1, j packets in queue 2, k nuggets available
- According to state transition diagram, we can derive following state equations:

$$
\begin{aligned}
(\lambda_1+\lambda_2)x(0,0,0) &= \mu_2 x(0,1,1) && (1)\\
(\lambda_1+\lambda_2)x(0,0,1) &= \mu_1 x(1,0,0) && (2)\\
\lambda_1 x(0,1,0) &= \lambda_2 x(0,0,0) && (3)\\
(\lambda_1+\mu_2)x(0,1,1) &= \lambda_2 x(0,0,1)+\mu_1 x(1,1,0) && (4)\\
(\lambda_2+\mu_1)x(1,0,0) &= \lambda_1 x(0,0,0)+\mu_2 x(1,1,1) && (5)\\
\lambda_2 x(1,0,1) &= \lambda_1 x(0,0,1) && (6)\\
\mu_1 x(1,1,0) &= \lambda_1 x(0,1,0)+\lambda_2 x(1,0,0) && (7)\\
\mu_2 x(1,1,1) &= \lambda_1 x(0,1,1)+\lambda_2 x(1,0,1) && (8)\\
\sum_{i=0}^{1}\sum_{j=0}^{1}\sum_{k=0}^{1} x(i,j,k) &= 1. && (9)
\end{aligned}
$$

- P_d : drop rate of own packets

$$P_d = x(0,1,0)+x(0,1,1)+x(1,1,0)+x(1,1,1)$$



- If $\lambda_1 = \lambda_2 = \hat{\lambda}$

$$P_d = \frac{\hat{\lambda}^3}{\Delta}(4\hat{\lambda}^3\mu+4\hat{\lambda}^2(\mu^2-\mu_1\mu_2)+3\hat{\lambda}(\mu_1^2\mu_2+\mu_1\mu_2^2)+\mu_1^2\mu_2^2).$$

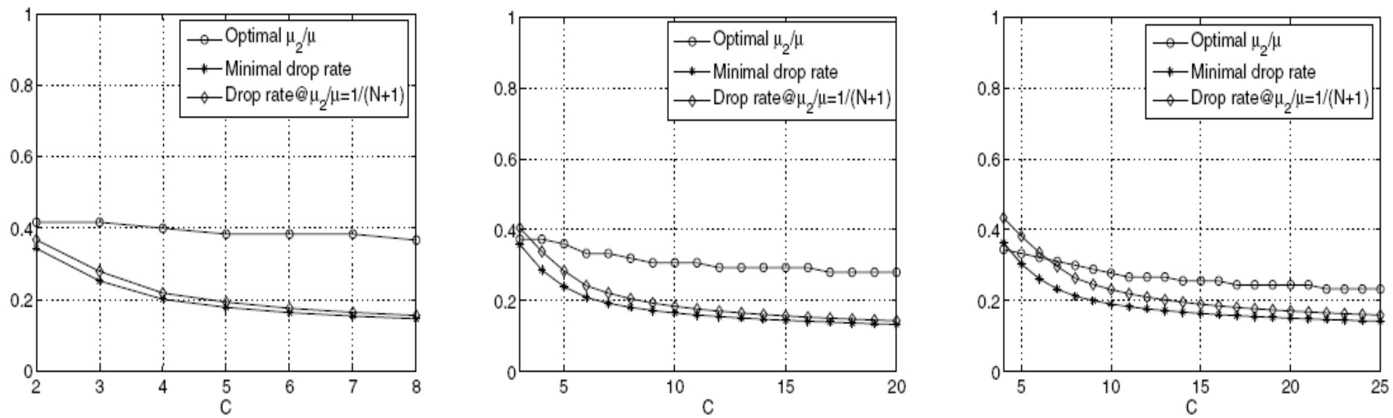
- The optimal $\mu_1 = \mu_2 = \mu/2$

GENERAL QUEUING MODEL

- Markovian model can be extended to general case with arbitray M_1,M_2,C,N.
- Markovian model has 3 dimensions, the max value for each dimension is M_1 , M_2, C respectively.
- Each state (i,j,k) has several transitions to other states. The state transition follow several simple patterns as shown below:

1. For $0 \leq i \leq M_1 - 1, 0 \leq j \leq M_2, 0 \leq k \leq C$, a transition from (i, j, k) to $(i + 1, j, k)$ with a rate of λ_1, which represents the reception of a packet in Queue 1;
2. For $0 \leq i \leq M_1, 0 \leq j \leq M_2 - 1, 0 \leq k \leq C$, a transition from (i, j, k) to $(i, j + 1, k)$ with a rate of λ_2, which represents the arrival of a self generated packet;
3. For $1 \leq i \leq M_1, 0 \leq j \leq M_2, 0 \leq k \leq C - 1$, a transition from (i, j, k) to $(i - 1, j, k + 1)$ with a rate of μ_1, which represents the transmission of a packet in Queue 1 and the gain of one nugget;
4. For $0 \leq i \leq M_1, 1 \leq j \leq M_2, N \leq k \leq C$, a transition from (i, j, k) to $(i, j - 1, k - N)$ with a rate of μ_2, which represents the departure of a self generated packet and the deduction of N nuggets.

NUMERIC RESULTS

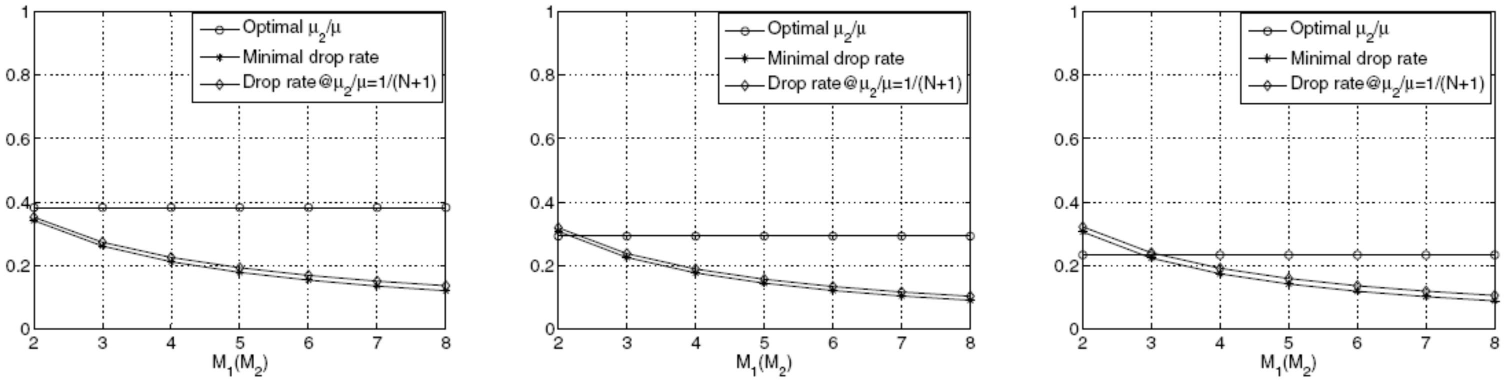


(a) $N = 2, \mu = 12$, and $\lambda_1 = 2\lambda_2 = 6$. (b) $N = 3, \mu = 15, \lambda_1 = 3\lambda_2 = 9$. (c) $N = 4, \mu = 18, \lambda_1 = 4\lambda_2 = 12$.

Impact of C on optimal $\frac{\mu_2}{\mu}$, with $M_1 = M_2 = 5$, $\lambda_2 = 3$, $\lambda_1 = N\lambda_2$.

- The drop rate does not change much when C is greater than certain value.
- When C is sufficient large, the dropping rate at $\frac{\mu_2}{\mu} = \frac{1}{N+1}$ is close to the minimal drop rate

NUMERICAL RESULTS



(a) $N = 2, \mu = 12$, and $C = 5$. (b) $N = 3, \mu = 15$, and $C = 15$. (c) $N = 4, \mu = 18$, and $C = 25$.

Impact of $M_1(M_2)$ on optimal $\frac{\mu_2}{\mu}$ with $\lambda_2 = 3$, $\lambda_1 = N\lambda_2$.

- The drop rate does not change much when M is greater than certain value.
- When M is sufficient large, the dropping rate at $\frac{\mu_2}{\mu} = \frac{1}{N+1}$ is close to the minimal drop rate

NUMERICAL RESULTS

- Under small C and/or M, the optimal μ_2/μ deviates from 1/(N+1). The larger the N, the bigger the deviation.
  - When C is small, a node can accumulate C nuggets quickly and refuses relaying data packets
  - When M is mall, the queue is more likely to overflow
- When C and M are large enough, the optimal μ_2/μ converges to 1/(N+1).
  - It is reasonable since it consumes N nuggets to transmit one self-generated packet. Thus the optimal ratio should be around 1/(N+1).

DISCUSSION

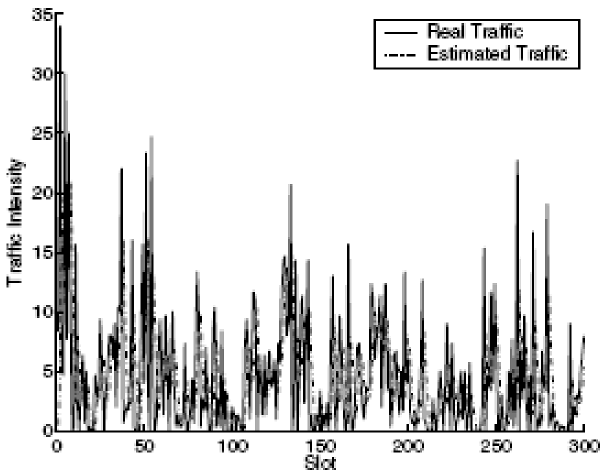
- In order to using the queuing analysis model, parameters (λ_1 , λ_2 ,μ, M_1, M_2, C, N) should be known beforehand
  - M_1, M_2, C are pre-determined by the incentive mechanism
  - λ_2 is the arrival rate of self-generated traffic, which is known
  - λ_1 ,μ, N are dynamic and need more work
- Sliding window-based linear autoregressive model is employed to estimate λ_1
- μ = W/(K+1), W: total bandwidth, K: neighbors number
- N depends on the routing path selection

NETWORK SIMULATION

Default Simulation Setup

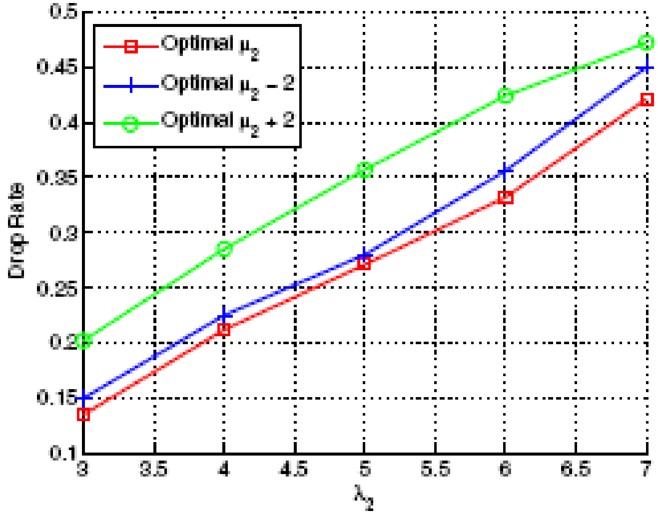
Number of Mobile Nodes	30
Area	100m*100m
Radio Range	30m
W	180 pkts/sec
λ_2	5 pkts/sec
C	80
M_1/M_2	25
Mobile Pattern	Random way point

$$\lambda_1'(n) = 0.5\lambda_1(n-1) + 0.3\lambda_1(n-2) + 0.2\lambda_1(n-3)$$



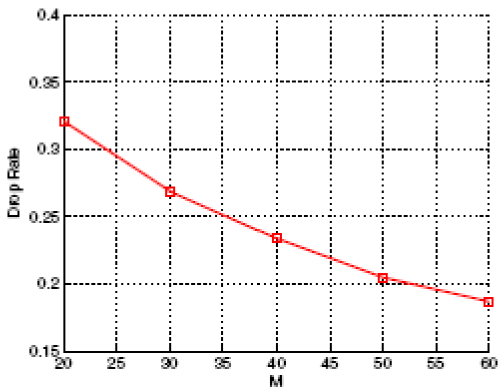
Linear autoregressive Estimation of forwarding traffic

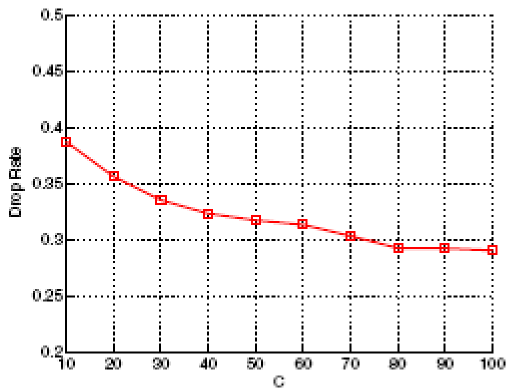
NETWORK SIMULATION



- The figure shows the network-wide average drop rate under different traffic load (λ_2) and different bandwidth allocation schemes.
- The drop rate increases with the increase of $\lambda_{2.}$
- Lowest drop rate achieved when μ_2 equals to optimal value derived by the Markov model.
- The observation testifies the correctness of the model and effectiveness of the credit-based incentive scheme.

NETWORK SIMULATION





- The left figure shows the impact of M.
- With the increase of M, the probability of dropout due to buffer overflow decreases.
- When M is sufficient large, the further increasing queue size doesn’t help much.

- The right figure shows the impact of C.
- With the increase of C, the drop rate decreases.
- When C is sufficient large, data delivery is no longer improved by increasing C, since the consumption and earning of nuggets at a node have reached a dynamic balance.

CONCLUSION

- An credit-based incentive mechanism is proposed to stimulate the cooperation among selfish nodes.
- Markov chain model is established to analyze the packet dropping probability, with given total bandwidth, buffer space, and the maximum credit.
- Bandwidth allocation has been optimized so that the dropping probability of a nodes' own packets is minimized.
- Considering the bandwidth constraint is a main contribution of the work.
- Simulation results show that the approach can effectively enable cooperation among selfish nodes and minimize overall packet dropping probability.

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QUESTION AND ANSWER