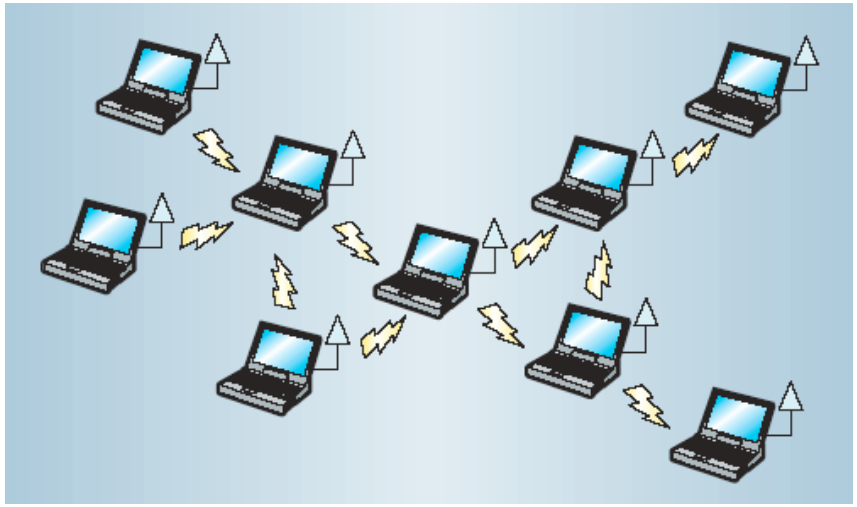
Rethinking Incentives for Mobile Ad Hoc Networks

By
E Huang, J Crowcroft & I Wassell
Richard Gibbens, Frank Kelly, Sven Östring

Laboratory of Communication Engineering
&
Computer Laboratory & Stats Lab
University of Cambridge

Mobile Ad Hoc Networks (MANETs)



- Consist of a set of self-organized, decentralized, mobile hosts that roam at will and communicate directly with each other
- A mobile host has to work as a router and cooperate with other hosts to find routes and relay messages
- If battery power, bandwidth, and other resources are scarce, selfish users may not wish to forward packets for other users
- Mesh (GuiFi) = fixed version

Incentives

- Encourage users to cooperate
  - Token Based Incentive Systems
  - Trust Management Systems
- Incentive systems have inherent flaws that make them difficult and undesirable to implement in practice
- Some may backfire by offering an incentive to cheat the incentives system
- Nice use case of Peer Production –
- Removes need for central provider

What is the problem?

- **Networks** – Mobile Ad Hoc, collaboration needed to form multi-hop routes
- **Pricing** – to provide incentives for the collaboration, i.e. reward for forwarding traffic for other nodes
- **Modeling –** apply existing rate control in wired networks, and resource control in wireless networks.

Generality of Problem

- Resource pooling in networks –
- Congestion control in the internet
- Congestion pricing in roads
- Academic paper peer review process
- Fancy math from control theory, (price is feedback)
- From optimisation models (also seen in eco-systems)
- C.f. Lyapunov etc
- Seen in some market regulation proposals

Math!

- $\mathcal{R}^{\mathcal{S}}(s)$ ubset of routes that originate at s
- $\mathcal{R}^{\mathcal{D}}(d)$ ubset of routes that terminate at d
- $x_s = \sum_{r \in \mathcal{R}^{\mathcal{S}}(s)} y_r$ otal flow from source s
- Capacity usage:

$$c_j = \sum_{\substack{r: j \in r, \text{ and} \\ r \in \mathcal{R}^{\mathcal{S}}(j) \cup \mathcal{R}^{\mathcal{D}}(j)}} y_r + \sum_{\substack{r: j \in r, \text{ and} \\ r \notin \mathcal{R}^{\mathcal{S}}(j) \cup \mathcal{R}^{\mathcal{D}}(j)}} 2y_r$$

$$c_j \leq C_j, \quad \forall j \in \mathcal{N}$$

- Power consumed:

$$\gamma_j = \sum_{r \in \mathcal{R}^{\mathcal{S}}(j)} y_r e^{(tx)}_{j f_{rj}} + \sum_{r \in \mathcal{R}^{\mathcal{D}}(j)} y_r e^{(rx)} + \sum_{\substack{r: j \in r, \text{ and} \\ r \notin \mathcal{R}^{\mathcal{S}}(j) \cup \mathcal{R}^{\mathcal{D}}(j)}} y_r \left(e^{(rx)} + e^{(tx)}_{j f_{rj}} \right)$$

$$\gamma_j \leq \Gamma_j, \quad \forall j \in \mathcal{N}$$

More Math!!

- Willing-to-pay: $$x_s(t) = \sum_{r \in \mathcal{R}^S(s)} y_r(t) = \frac{w_s(t)}{\min_{r \in \mathcal{R}^S(s)} \sum_{j \in r} \mu_{jr}(t)}$$
- Prices along the routes:

$$\mu_{jr}(t) = \begin{cases} e^{(tx)}_{jf_{rj}} \mu^P_j(t) + \mu^B_j(t), & j \text{ is the source node on route } r, \\ \left(e^{(rx)} + e^{(tx)}_{jf_{rj}}\right) \mu^P_j(t) + 2\mu^B_j(t), & j \text{ is a transit node for route } r, \\ e^{(rx)} \mu^P_j(t) + \mu^B_j(t), & j \text{ is the destination node on route } r. \end{cases}$$

$$\frac{d}{dt}\mu^B_j(t) = \frac{\kappa \mu^B_j(t)}{C_j}\left(c_j(t) - C_j\right) \qquad \frac{d}{dt}\mu^P_j(t) = \frac{\kappa \mu^P_j(t)}{\Gamma_j}\left(\gamma_j(t) - \Gamma_j\right)$$

- Credit balance: $$\frac{db_s}{dt} = -\beta\left(b_s(t) - 1\right) - w_s(t) + \sum_{r: s \in r} y_r \mu_{sr}(t)$$

$$w_s(t) = \alpha_s b_s(t)$$

Simulations

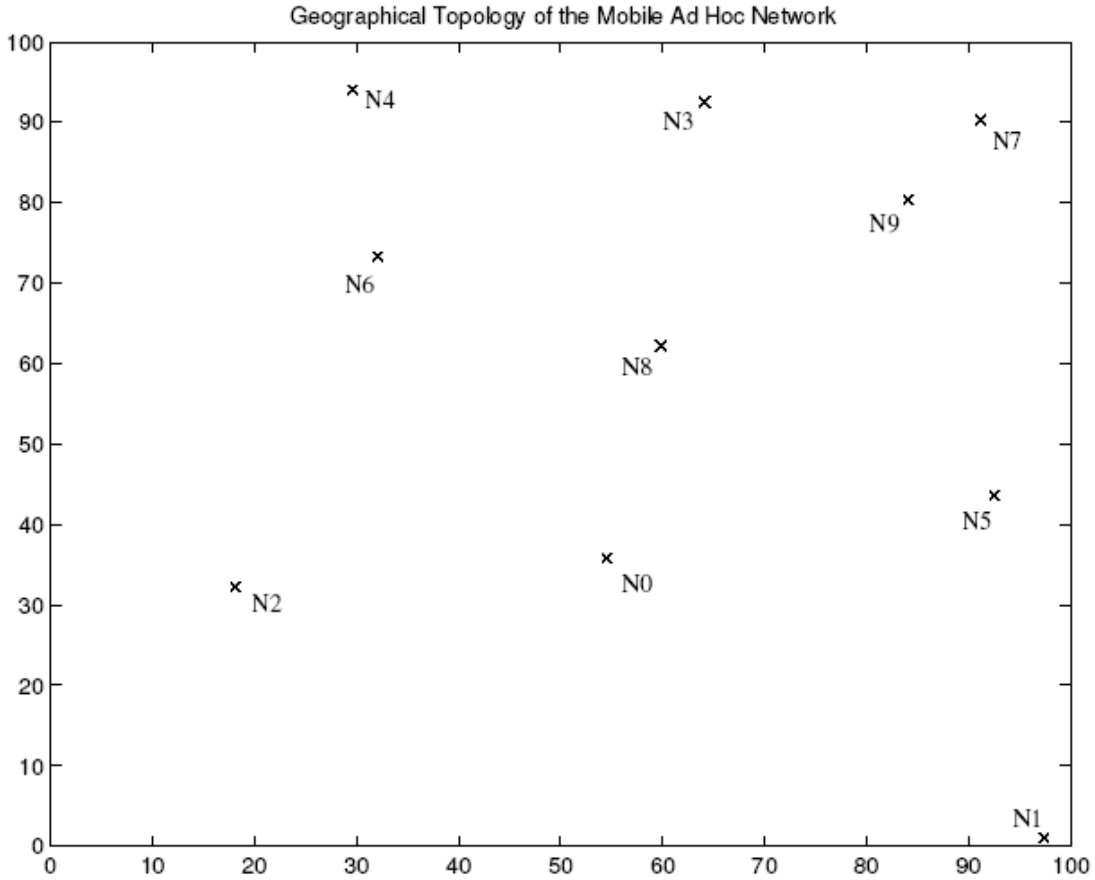
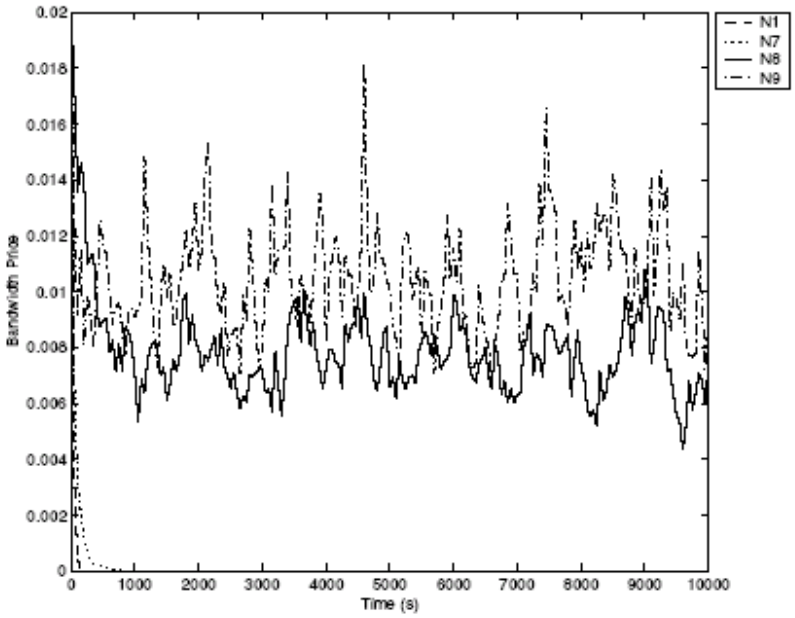
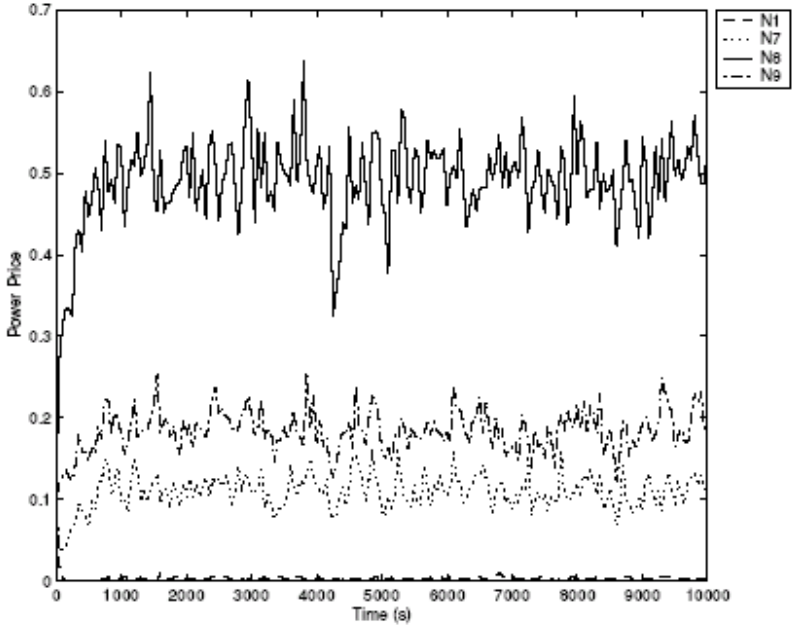


Figure 1: Topology of the mobile ad hoc network.

Static Networks Results (1)

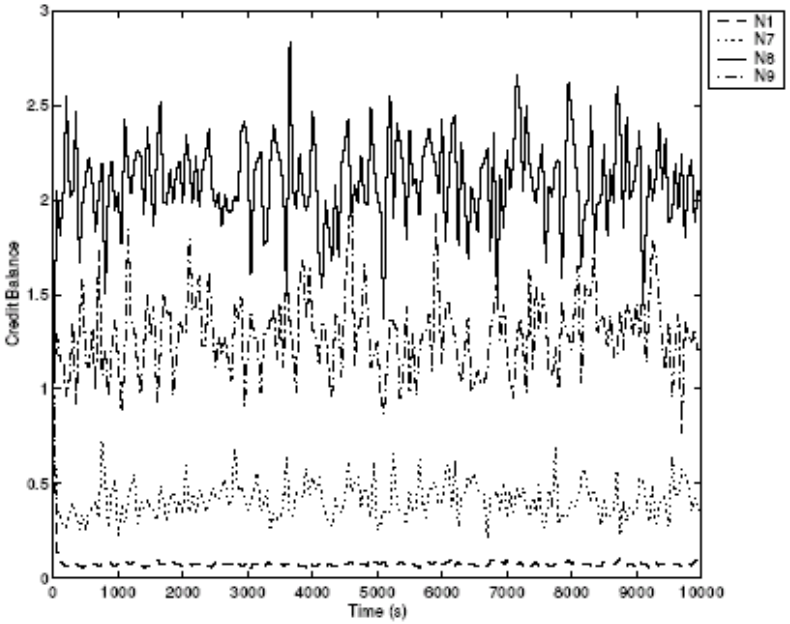


(a) Bandwidth Prices

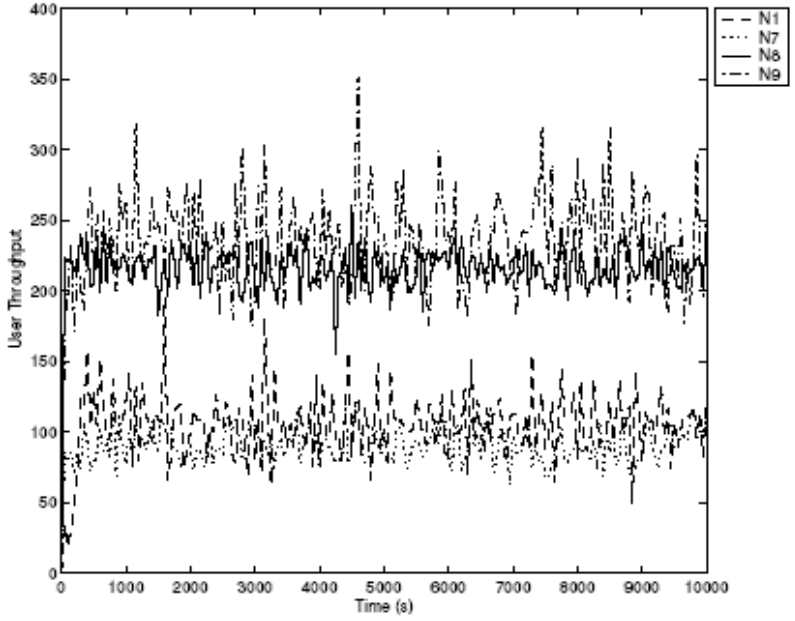


(b) Power Prices

Static Networks Results (2)

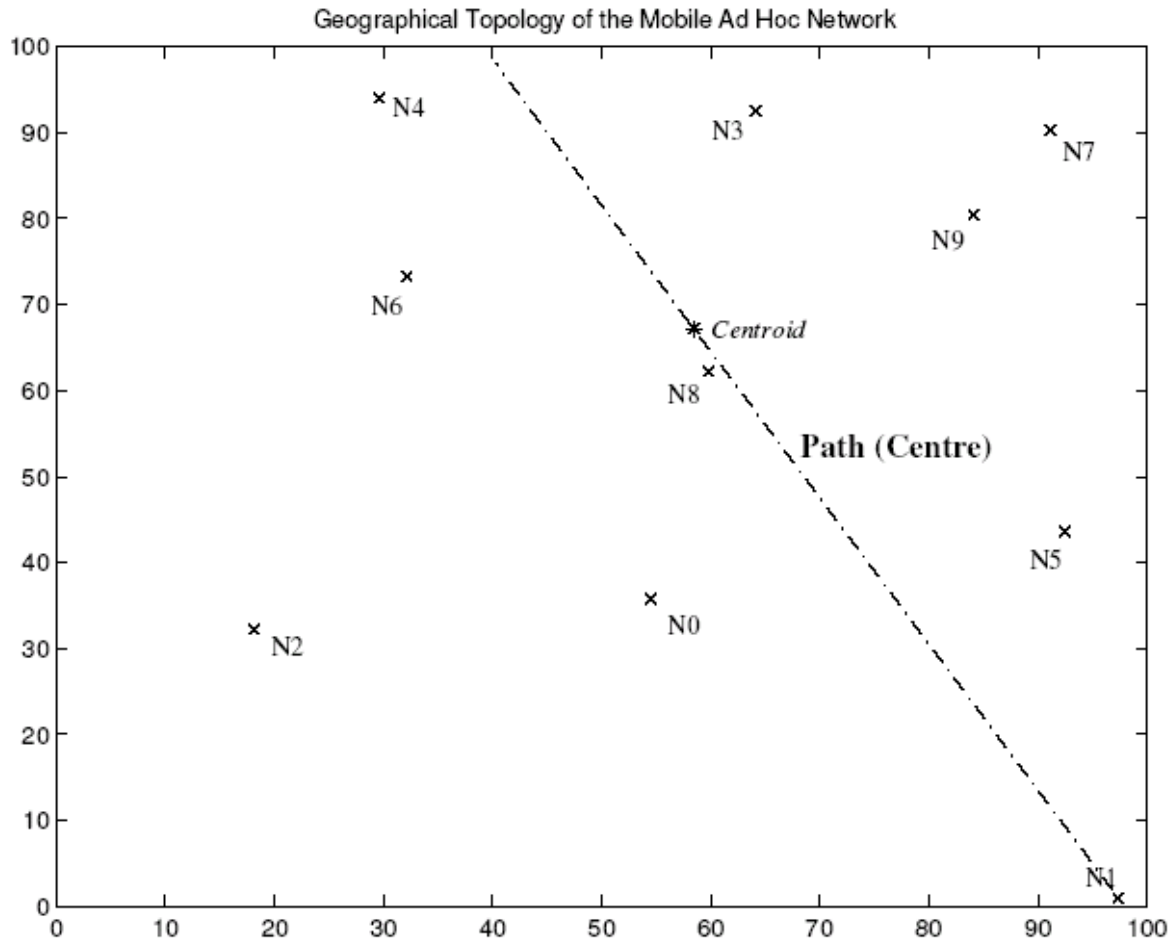


(a) Credit Balances

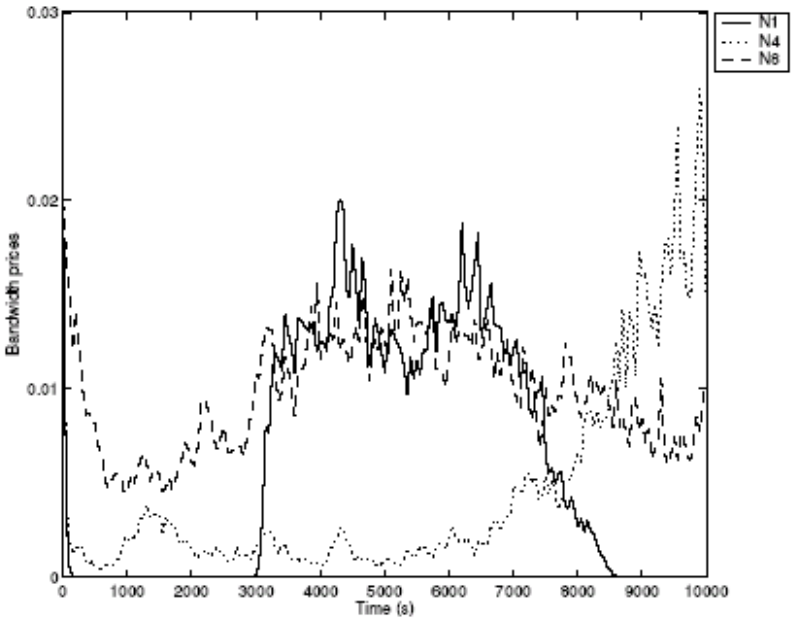


(b) Throughputs

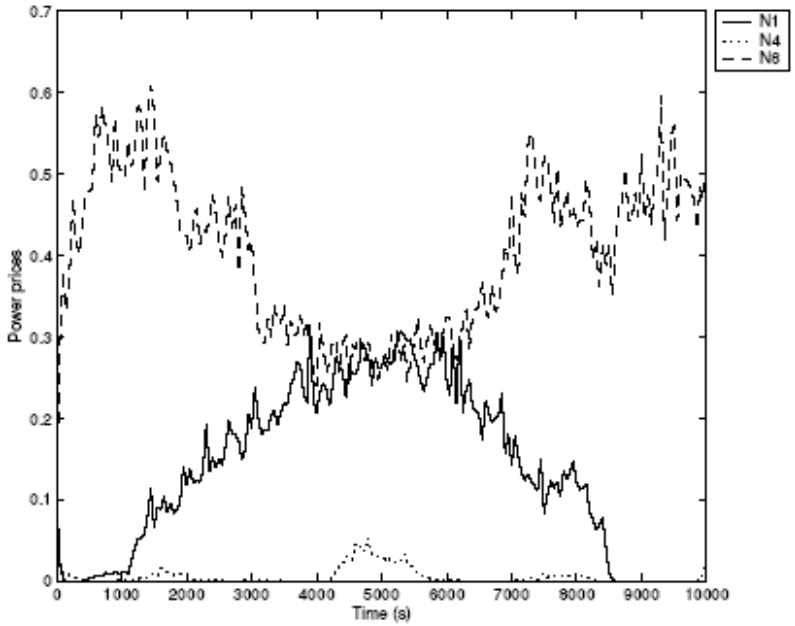
Dynamic Networks



Dynamic Networks Results(1)

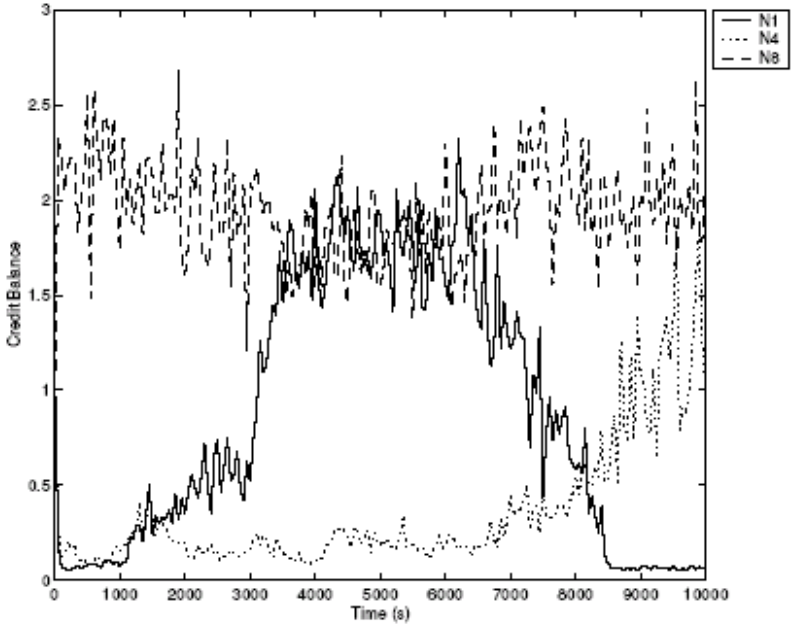


(a) Bandwidth Prices

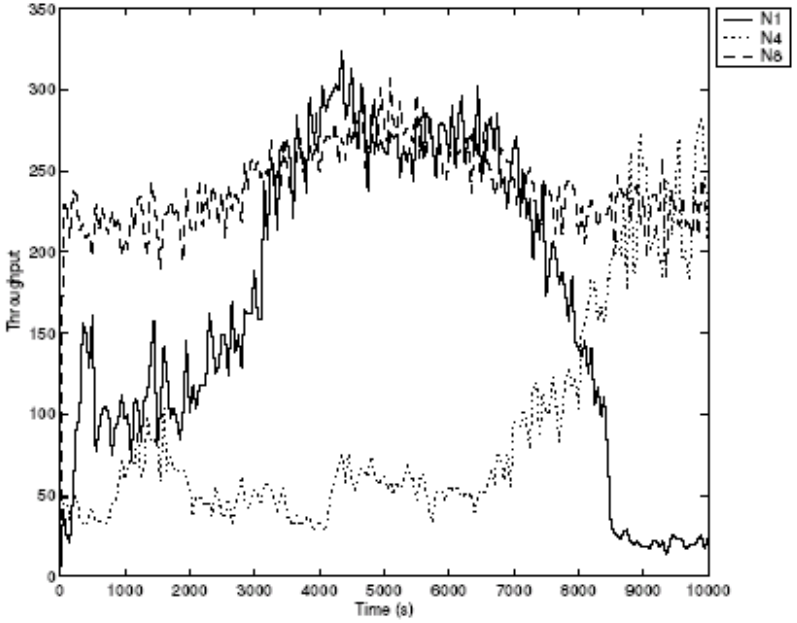


(b) Power Prices

Dynamic Networks Results(2)

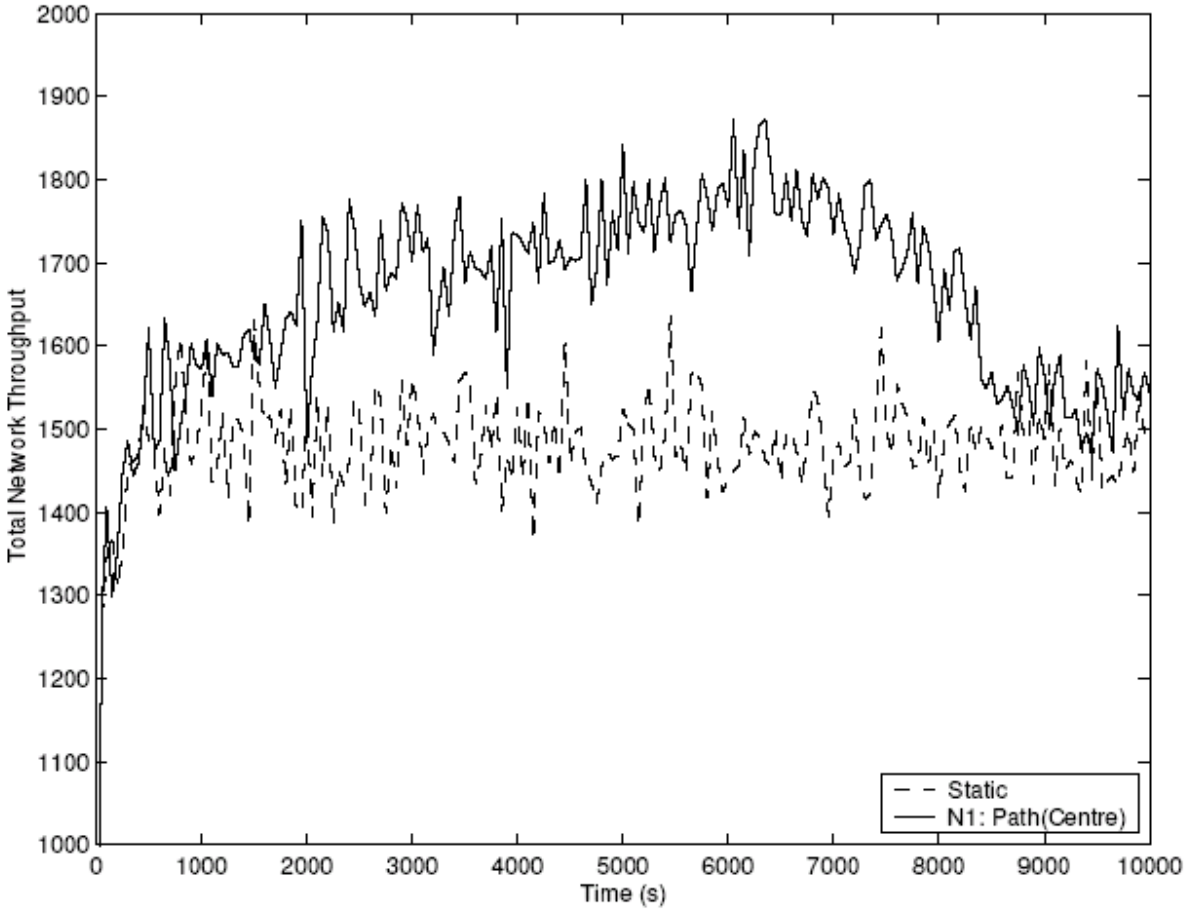


(a) Credit Balances



(b) Throughputs

Dynamic Networks Results(3)



Dynamic Networks pb

- Churn in membership
  - Bootstrap new nodes initial credit (1 coin)
  - Reflate currency if nodes leave with coins

Conclusions

- Pricing schemes can recover the cost of resources at transit nodes
- Further work:
  - delays in the network such as propagation delay;
  - interference need to be taken into consideration.

Token Based Incentive Systems

- Use notional credit to pay off users for congestion costs; earn credit by forwarding for other users
- Limits amount of data that can be sent at any given time. Buffering only works if buffer is large enough and no delay constraints on packets. Hence somewhat inefficient for real time communications
- Users on outskirts of network put at a disadvantage

Token Based Incentive Systems

- Estimation of hop number takes up resources. If done incorrectly results in dropped packets, wasted credit and wasted energy
- Balance of token levels
- Using real money as credit provides more incentive to cheat and requires centralisation or tamper proof hardware
- Who pays?
- Adds complexity

Trust Management Systems

- Nodes within network exchange reputation information
- Takes up resources
- Relying on second hand information can lead to false accusations or cheating via collusion
- Obtaining authentication and trust information about accusing node is very hard to achieve; may not be possible for dynamic short lived networks

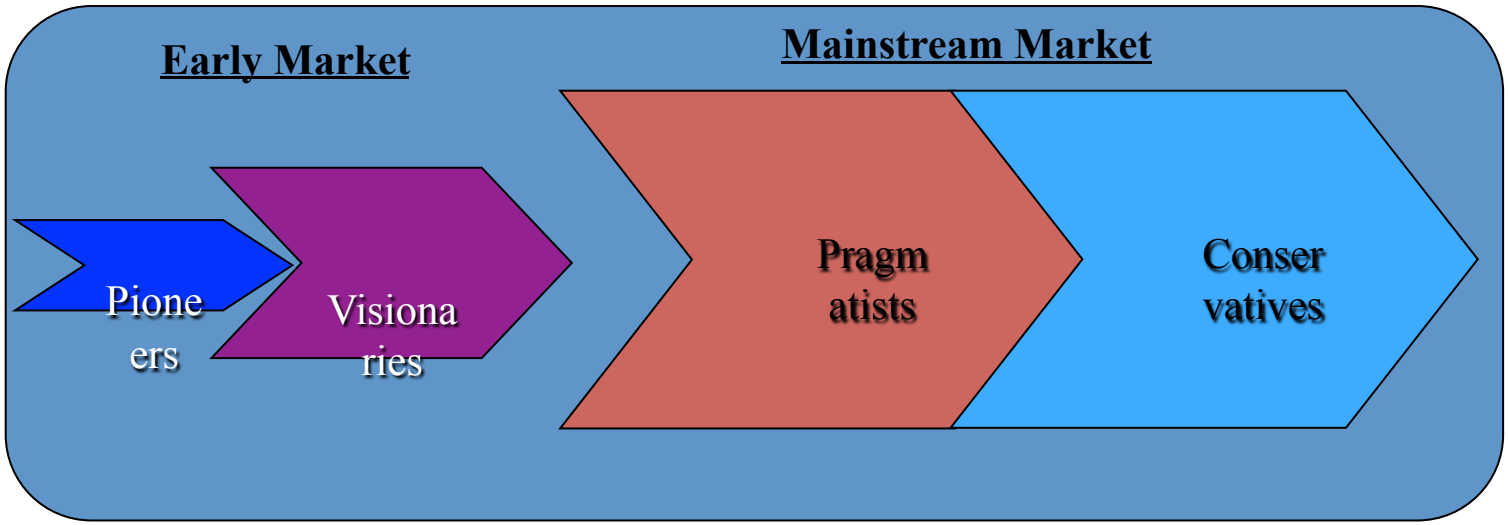
Transparency vs. Choice

- Incentives seek to induce cooperation
- We want users to choose to forward and keep devices on
- The more choice there is, the more complex for user
- Given that incentives system makes forwarding mandatory there is little point of giving users a choice in the matter

Are incentives really necessary?

- Cooperation is only an issue when resources are scarce
- Chicken and egg
- MANETs require phased deployments and are unlikely to be used for generic applications in early stages
- Vital that overly complex incentive systems do not cause early adopters to shun MANETs
- MANETs vs. P2P
- Decentralised allocation of identifiers and unforgeable tokens is generally an unsolved technical problem

A Phased Out Solution



Adoption Cycle for Mobile Ad Hoc Networks

- Pioneers are enthusiastic users, more interested in exploring technology than benefiting from it
- Visionaries see the potential in new technology and are willing to help to get a head start in reaping the benefits
- Pragmatists want a complete solution that works
- Conservatives want products that are cheap and simple. They hop onto the bandwagon only when they have no choice
- Only at later points in the cycle do incentive systems make sense. At this point it is better understood how people use and abuse systems. Even then incentives can stem from common interest.

Why We Don't Need Incentive Systems Anyway

- Main need for incentives vs. hardwired behaviour is to prevent tampering
- But majority of users will only cheat when it is beneficial to them and easy to do
- Playstation has fallen victim to large scale tampering
- With PS there are compelling reasons for consumers to pay for modification and criminal organisations to provide these services
- Benefit from modifying ad hoc devices is mainly battery power savings

Why We Don't Need Incentive Systems Anyway

- Unclear that users would go out of their way to modify devices vs. buying a spare battery
- Different devices for different applications will need unique modifications
- It would be an expensive and complex task to reverse engineer all these devices
- Without a ready market, criminal organisations have no incentive to offer modifications
- Modifying ad hoc devices is not sustainable. The less nodes cooperate the worse the network performance

Conclusion

- Incentive systems may be better left till ad hoc networks enter mainstream markets
- They should be tailored to the needs of individual applications rather than generic solutions
- There is no perfect solution; it is more important at this time to allow ad hoc networks to grow and develop than to stifle it with overly complex solutions