Exploiting Social Preferences for Congestion Control in Opportunistic Networks

Dimitrios-Georgios Akestoridis, Nikolaos Papanikos, and Evangelos Papapetrou

Department of Computer Science and Engineering,
University of Ioannina, Greece

The 10th IEEE International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob '14)

Outline

Background

- Opportunistic networks
  - Connectivity appears in the form of contacts
  - Human mobility and sparse topology
  - An end-to-end path is rarely available
- Prominent routing approach
  - Greedy decisions on a contact basis
  - Use of a utility metric that captures the fitness of the nodes
  - Forward each packet to the most suitable carrier
- Highly unbalanced traffic load distribution
  - Mainly due to the heterogeneity of node utilities
  - A small fraction of nodes handles most of the traffic load
  - Degradation of performance due to packet drops

Related Work (pt. 1)

- Congestion control strategies for multi-copy schemes
  - The focus is on dynamic replication techniques and/or efficient dropping policies
  - Packet drops can be tolerated to some extent
- Congestion control strategies for single-copy schemes
  - The problem of congestion control in the single-copy case is far more challenging
  - Each packet drop automatically degrades the delivery ratio

Related Work (pt. 2)

- We can identify two types of congestion control strategies for single-copy schemes:
  - Those diverting traffic to alternative paths
  - Those enhancing fairness
- Autonomous Congestion Control (ACC)
  - The remaining storage space of each node is regarded as money and the packet transmissions as financial activities
  - Each node has to keep a detailed record of its buffer occupancy history
- FairRoute
  - The queue length of each node is used as an equivalent of its social status in order to distribute the traffic load fairly
  - It may increase the average delay significantly

Contributions

Motivation

A profitable trade-off between efficiency and fairness can be achieved.

- Adjustable Fairness
  - Combine fairness-related incentives with utility-based routing principles to reduce end-to-end delay
  - By increasing the likelihood of delivering packets, we reduce the traffic load in the network and alleviate congestion
- *Congestion Control with Adjustable Fairness (CCAF)*
  - Our approach is to be as fair as possible, while taking advantage of the high-utility nodes wisely
  - CCAF can achieve low end-to-end delay at the expense of a reasonably low cutback in fairness
  - We rely on the social preferences of the nodes for dynamically tuning the trade-off between efficiency and fairness

Outline

CCAF: Forwarding Step Importance

- To capture the *importance of each forwarding step*, we use a normalized utility value $U_{i,j}(d)$ which is defined as:

$$U_{i,j}(d) = \frac{\mathrm{u}_j(d) - \mathrm{u}_i(d)}{\mathrm{u}_j(d) + \mathrm{u}_i(d)}$$

  where:

  - i and j are two nodes in contact
  - $\mathrm{u}_i(d)$ and $\mathrm{u}_j(d)$ denote their utilities
  - d denotes the destination of a packet

- Observe that:
  - $U_{i,j}(d) = 1$ when $\mathrm{u}_i(d) = 0$ and $\mathrm{u}_j(d) > 0$
  - $U_{i,j}(d) \rightarrow 1$ when $\mathrm{u}_j(d) \gg \mathrm{u}_i(d)$
  - $U_{i,j}(d) \rightarrow 0$ when $\mathrm{u}_j(d) \approx \mathrm{u}_i(d)$

CCAF: Custody Acceptance Criterion

- Node i will forward a packet destined for node d to node j, provided that R_j is enough to store it, when the following condition is true:

$$\left(U_{i,j}\left(d\right) > 0\right) \wedge \left(\frac{R_j}{B_j} > \left(1 - \left(U_{i,j}\left(d\right)\right)^{\delta}\right)\frac{R_i}{B_i}\right)$$

  where:
  - R_i denotes the remaining storage space of i
  - B_i denotes the total storage capacity of i
  - $U_{i,j}\left(d\right)$ is the normalized utility value
  - δ is a tunable parameter

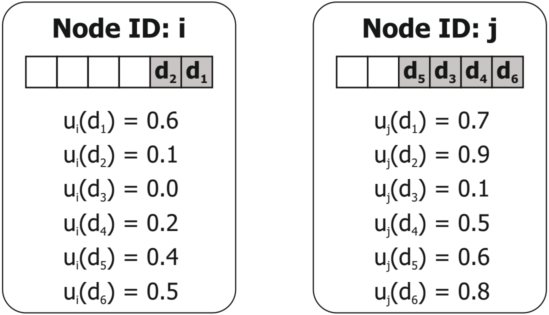
- The rationale behind using $1 - \left(U_{i,j}\left(d\right)\right)^{\delta}$ in the storage-related criterion is to be able to *relax* or *enforce* it based on the importance of the forwarding opportunity

- The introduction of δ allows us to adjust our approach either towards high efficiency or absolute fairness

CCAF: An Example

- Consider the following example, where nodes i and j are in contact and they carry some packets for the destination nodes $d_1, \ldots, d_6$

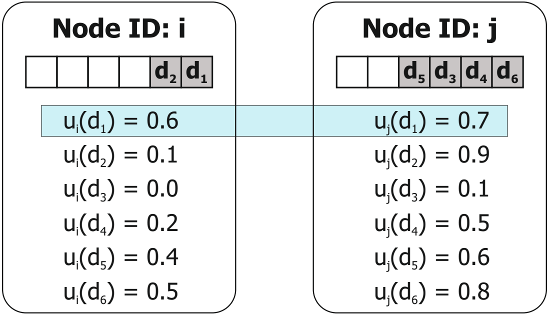
$$(U_{i,j}(d) > 0) \wedge \left(\frac{R_j}{B_j} > \left(1 - (U_{i,j}(d))^{\delta}\right) \frac{R_i}{B_i} \right)$$



CCAF: An Example

- Assuming that $\delta = 1$, when $U_{i,j}(d) \to 0$ the packet will be forwarded to node j only if it also contributes at balancing the traffic load

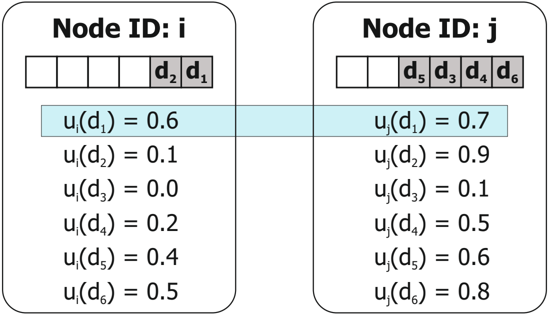
$$\left(\frac{\mathrm{u}_j(d) - \mathrm{u}_i(d)}{\mathrm{u}_j(d) + \mathrm{u}_i(d)} > 0\right) \wedge \left(\frac{R_j}{B_j} > \left(1 - \frac{\mathrm{u}_j(d) - \mathrm{u}_i(d)}{\mathrm{u}_j(d) + \mathrm{u}_i(d)}\right)\frac{R_i}{B_i}\right)$$



CCAF: An Example

- Assuming that $\delta = 1$, when $U_{i,j}(d) \rightarrow 0$ the packet will be forwarded to node j only if it also contributes at balancing the traffic load

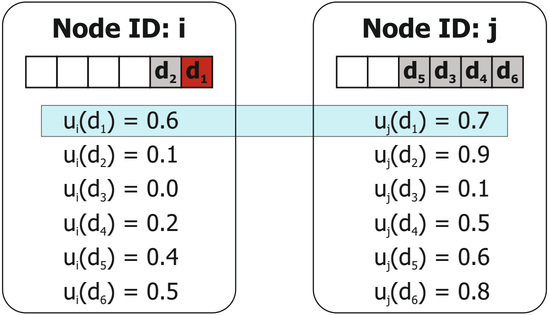
$$\left(\frac{0.7 - 0.6}{0.7 + 0.6} > 0\right) \wedge \left(\frac{2}{6} > \left(1 - \frac{0.7 - 0.6}{0.7 + 0.6}\right)\frac{4}{6}\right)$$



CCAF: An Example

- Assuming that $\delta = 1$, when $U_{i,j}(d) \to 0$ the packet will be forwarded to node j only if it also contributes at balancing the traffic load

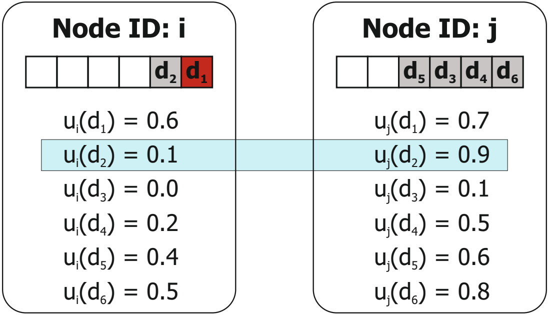
$$\left(\frac{1}{13} > 0\right) \wedge \left(\frac{26}{78} > \frac{48}{78}\right)$$



CCAF: An Example

- Assuming that $\delta = 1$, when $U_{i,j}(d) \rightarrow 1$ we may relax the load balancing to forward the packet to node j

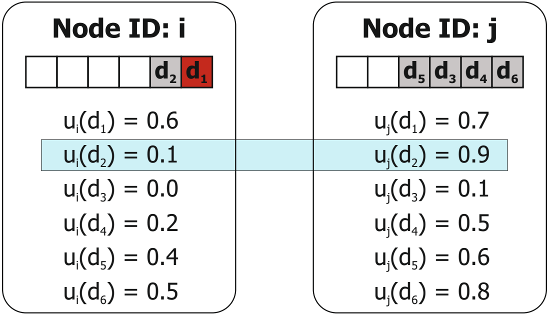
$$\left(\frac{\mathrm{u}_j(d) - \mathrm{u}_i(d)}{\mathrm{u}_j(d) + \mathrm{u}_i(d)} > 0\right) \wedge \left(\frac{R_j}{B_j} > \left(1 - \frac{\mathrm{u}_j(d) - \mathrm{u}_i(d)}{\mathrm{u}_j(d) + \mathrm{u}_i(d)}\right)\frac{R_i}{B_i}\right)$$



CCAF: An Example

- Assuming that $\delta = 1$, when $U_{i,j}(d) \to 1$ we may relax the load balancing to forward the packet to node j

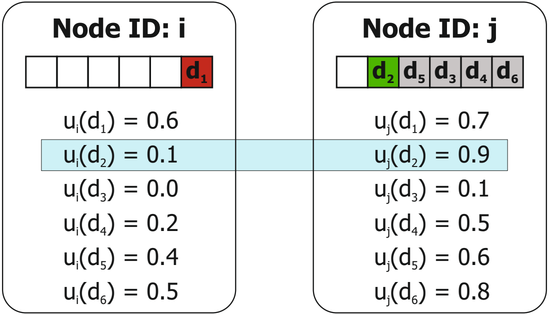
$$\left(\frac{0.9-0.1}{0.9+0.1} > 0\right) \wedge \left(\frac{2}{6} > \left(1 - \frac{0.9-0.1}{0.9+0.1}\right)\frac{4}{6}\right)$$



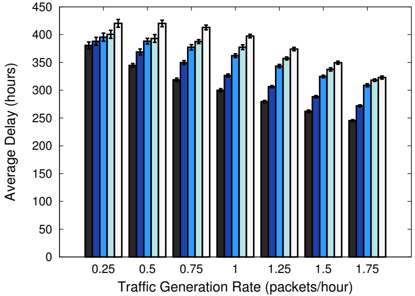
CCAF: An Example

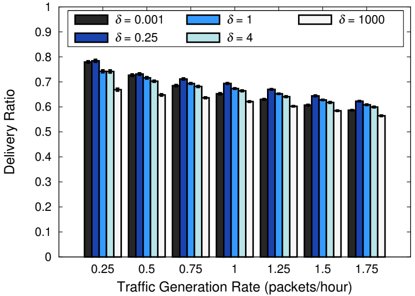
- Assuming that $\delta = 1$, when $U_{i,j}(d) \to 1$ we may relax the load balancing to forward the packet to node j

$$\left(\frac{8}{10} > 0\right) \wedge \left(\frac{20}{60} > \frac{8}{60}\right)$$

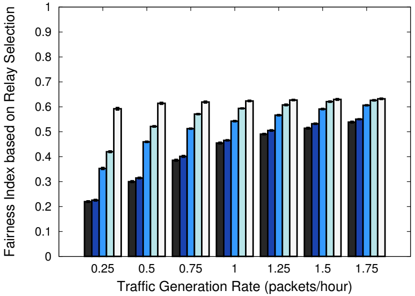


CCAF: The trade-off between Efficiency and Fairness





- **Mobility trace:** Reality Mining
- Fixed values of δ
- A profitable trade-off is present when $\delta \in (0.25, 1]$



CCAF: Towards a Self-Configuring Method (pt. 1)

- We visualize δ as a parameter that describes the *social preferences* that each node has towards allocating its resources for the sake of others, which could change over time
- When $\delta \to 0$, the nodes behave altruistically because they are contributing all of their resources to help others achieve communication
- Selfish nodes would choose a high δ value, so that they could avoid using their resources to help other nodes
- We make the observation that a more efficient solution may result from a mixture of selfish, prosocial, and altruistic nodes

CCAF: Towards a Self-Configuring Method (pt. 2)

- Our approach is based on the idea that the nodes would prefer to allocate their resources according to their social ties
- To produce the aforementioned behavior, we use *similarity* to measure "friendship" to define $\delta_{i,j}(d)$ as:

$$\delta_{i,j}(d) = e^{-(Similarity_j(d) - Similarity_i(d))}$$

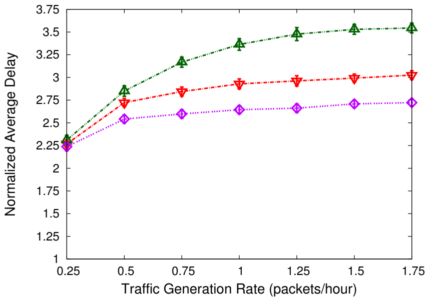
- Note that, $\delta_{i,j}(d) \rightarrow 0$ when the "friendship" between nodes j and d is much closer than that between i and d
- The nodes will act altruistically for their friends and selfishly for strangers

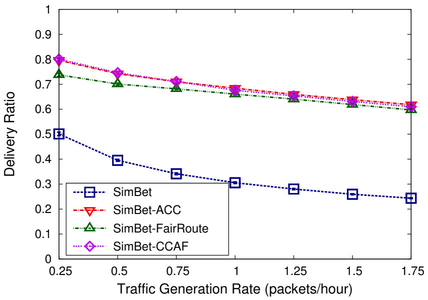
Outline

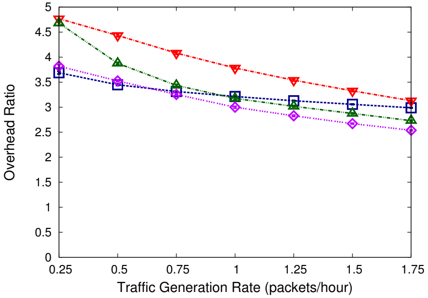
Simulation Setup

- Algorithms:
  - SimBet
  - SimBet-ACC
  - SimBet-FairRoute
  - SimBet-CCAF
- Mobility traces:
  - Reality Mining
  - Cambridge
- Network traffic:
  - Fixed-sized packets that are generated with a random pair of source and destination nodes
  - The traffic load ranges from low to high, based on the characteristics of each data set

Efficiency Evaluation (pt. 1)

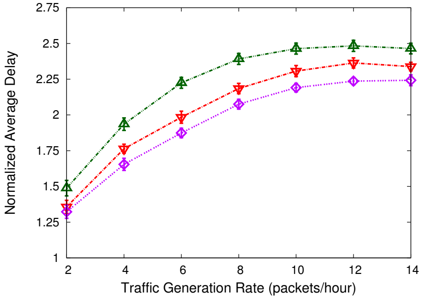


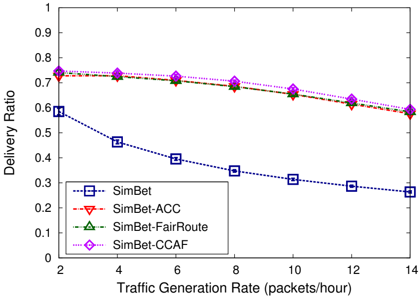




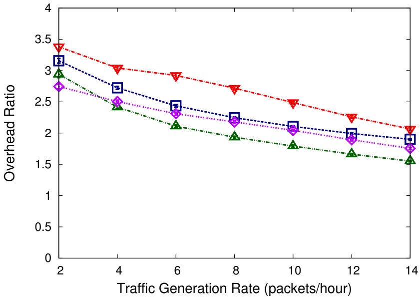
- **Mobility trace:** Reality Mining
- CCAF achieves the lowest average delay
- ACC induces the highest cost

Efficiency Evaluation (pt. 2)

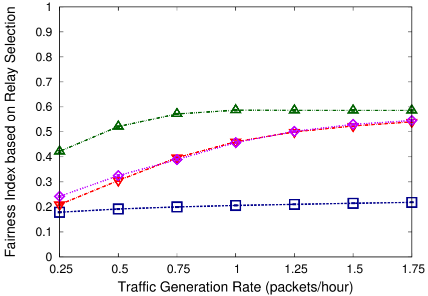


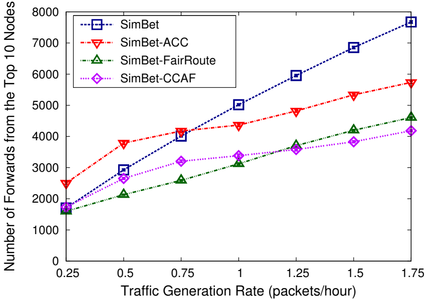


- **Mobility trace:** Cambridge
- CCAF achieves the lowest average delay
- ACC induces the highest cost

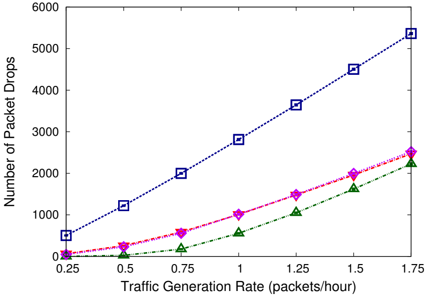


Fairness Evaluation (pt. 1)

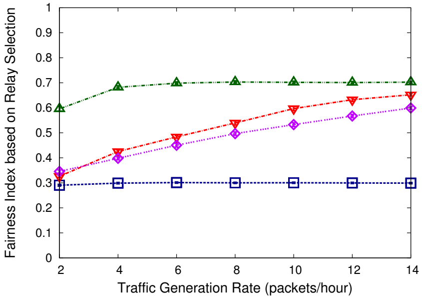


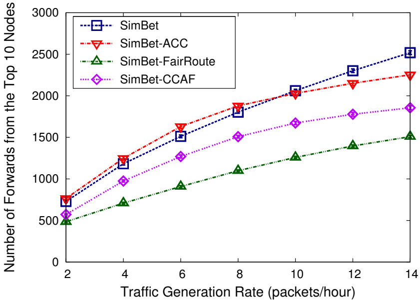


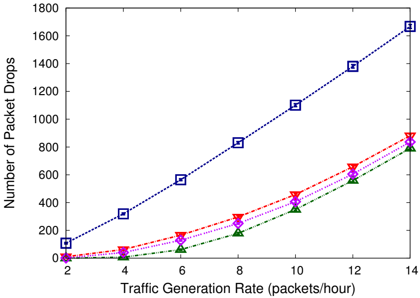
- **Mobility trace:** Reality Mining
- We use *Jain's Fairness Index*
- CCAF has a limited cutback in fairness under high traffic load



Fairness Evaluation (pt. 2)







- **Mobility trace:** Cambridge
- We use *Jain's Fairness Index*
- CCAF has a limited cutback in fairness under high traffic load

Outline

Conclusions and Future Work

- Conclusions
  - Traditional utility-based routing protocols overuse a small subset of nodes
  - It is critical to combine utility-based routing principles with custody acceptance criteria that are oriented towards fairness
  - CCAF provides a trade-off between high efficiency and absolute fairness, which can be fine-tuned through the tunable parameter δ
  - Our approach results in significant performance gains with a limited cutback in fairness by relying on the social preferences of the nodes in order to define δ
- Future Work
  - We intent to investigate other methods to define δ, based on local and network-wide information
  - An estimation of the number of replicas and the battery level of each device are some possible extensions