Incentive-Driven and Freshness-Aware Content Dissemination in Selfish Opportunistic Mobile Networks

Huan Zhou[1], Jie Wu[2], Hongyang Zhao[1], Shaojie Tang[2], Canfeng Chen[3], and Jiming Chen[1]

1. State Key Lab. of Industrial Control Technology, Zhejiang University, Hangzhou, China.
2. Department of Computer and Information Sciences, Temple University, USA.
3. Nokia Research Center, Beijing, China.

Presenter: Huan Zhou

Outline

- **Introduction**
- **Motivations**
- **Network Model**
- **Proposed Scheme ConDis**
- **Performance Evaluation**
- **Conclusion**

Outline

- **Introduction**
- Motivations
- Network Model
- Proposed Scheme ConDis
- Performance Evaluation
- Conclusion

Introduction

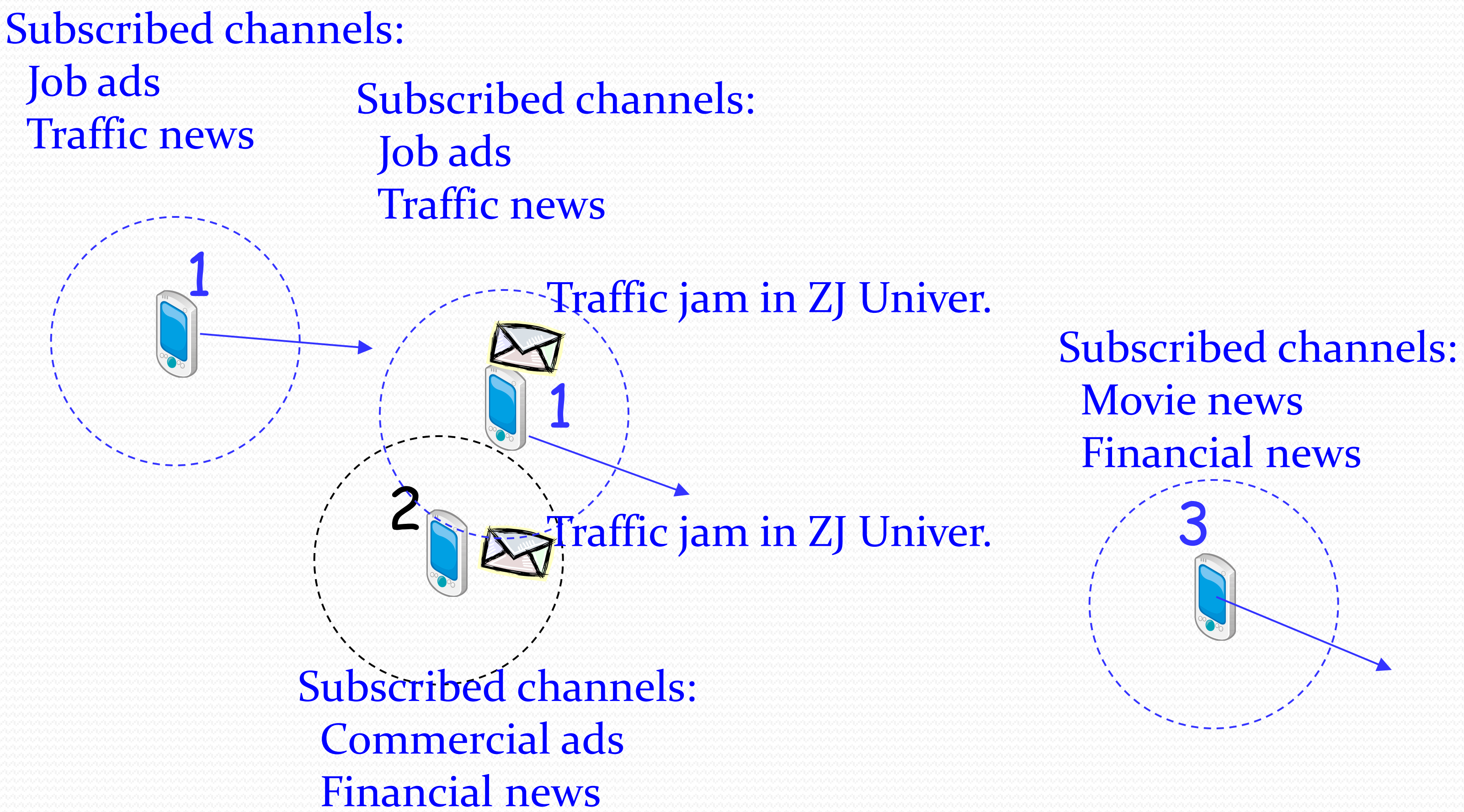
- Delay Tolerant Networks, Intermittently Connected Networks
- Consists of portable devices with bluetooth or wifi, such as smart phone, PDAs, laptops
- Intermittent connectivity
  - High dynamic time-varying topology
  - Contact: two nodes within the transmission range of each other
  - Store-carry-forward

Cont’d

- Content Dissemination: publish/subscribe scheme.
- Pub/sub scheme: high flexibility and adaptability when dealing with highly dynamic network topologies.
- Subscriber: express their interest without knowledge of the content generators’ specific ID.
- Publisher: generate contents to the network without specifying the destination ID.
- Goal: deliver contents from publishers to subscribers.
- Contents to be disseminated fall into several channels:
  - Sport news, Traffic news, Pop music and so on

Cont'd

- An Example of Pub/sub Content Dissemination in OppNets.



Outline

- Introduction
- **Motivations**
- Network Model
- Proposed Scheme ConDis
- Performance Evaluation
- Conclusion

Motivations

- Behaviors of nodes:
  - Cooperative: voluntarily store, carry, and forward others' contents
  - Selfish: only carry its own interested contents; not be willing to share its resources
- Existing works addressing selfishness:
  - Reputation-based; Credit-based; and Tit-For-Tat (TFT)-based schemes.
  - TFT only requires the principle of equal amounts of service.
- How to stimulate selfish nodes to participate into content dissemination and improve network performance under the TFT scheme?

Outline

- Introduction
- Motivations
- **Network Model**
- Proposed Scheme ConDis
- Performance Evaluation
- Conclusion

Network Model

- Node Contact Model: pair-wise inter-contact time in realistic traces follows an exponential distribution.
- Channel and Content Model:
  - Nodes need to express their interests towards different kinds of contents in a certain way, and accordingly subscribe to those channels;
  - Each published content includes (d, c, T_d, T);
- Assumptions:
  - The buffer size of nodes is the same;
  - Contents have the same volume capacity;

Outline

- Introduction
- Motivations
- Network Model
- **Proposed Scheme ConDis**
- Performance Evaluation
- Conclusion

Proposed Scheme ConDis

-Architecture of ConDis:

- The Architecture of ConDis:
  - Subscribed Channel Manager: keeps the channel information subscribed by its one-hop neighbors.
  - Buffer State Collector: collects the content information stored at its one-hop neighbors.
  - Content Utility Estimator: gives the definition of content utility.
  - Buffer Manager: manages contents in the buffer, and the cache management of a node is mainly based on the content utility.

Proposed Scheme ConDis

-Content Utility Estimator

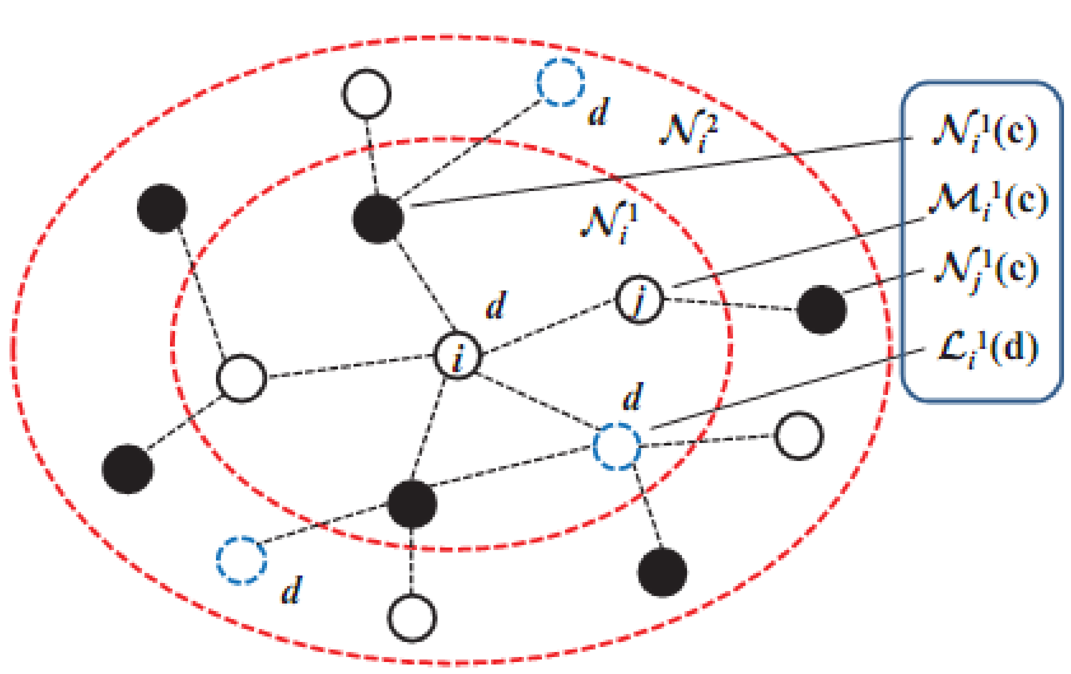
- Each content has an initial freshness value V when it is published by a certain node.
- The freshness value of a certain content d for a subscribed node i can be expressed as:

$$v_i(d) = \frac{R_d V}{T},$$

- R_d is the remaining valid time of content d; T is the TTL of content d.

Proposed Scheme ConDis
-Content Utility Estimator

- Illustrating the utility definition:



- We divide node *i*'s one-hop neighbors into three kinds:
  - Black-solid nodes $\mathcal{N}_i^1(c)$: interested in content *d*;
  - Black-hollow nodes $\mathcal{M}_i^1(c)$: not interested in content *d*;
  - Blue-dashed nodes $\mathcal{L}_i^1(d)$: already have obtained content *d*;

Proposed Scheme ConDis

-Content Utility Estimator

- The first kind will absolutely choose to request content d from node i;
- The second kind may also request content d from node i;
- $\mathcal{N}_i^1(c)$ → direct subscribed value $U_{di}(d)$.
- $\mathcal{M}_i^1(c)$ → indirect subscribed value $U_{indi}(d)$.
- The utility of a content d in channel c for node i is defined as:

$$U_i(d) = wU_{di}(d) + (1-w)U_{indi}(d),$$

- w in the range of [0, 1].

Proposed Scheme ConDis
-Content Utility Estimator

- For node $j \in \mathcal{N}_i^1(c)$, *j* will request content *d* from node *i* only when the following three conditions are met:
  - Node *j* will not receive content *d* from its one-hop neighbors before this content is time out.
  - Node *i* can deliver content *d* to *j* before this content is time out.
  - When content *d* is delivered to node *j* , node *i* should guarantee that this content is fresh.
- Then, we express the direct subscribed value $U_{di}(d)$ as:

$$U_{di}(d) = \sum_{j \in \mathcal{N}_i^1(c)} \frac{(R_d - ED_{ij})V}{T} \prod_{k \in \mathcal{L}_j^1(d)} [1 - Pr_{jk}(R_d)], \quad (3)$$

Proposed Scheme ConDis
-Content Utility Estimator

- Similarly, the indirect subscribed value $U_{indi}(d)$ can be expressed as:

$$U_{indi}(d) = \sum_{j \in \mathcal{M}_i^1(c)} \sum_{k \in \mathcal{N}_j^1(c)} \frac{(R_d - ED_{ik}^j)V}{T}, \qquad (4)$$

- Here, node j is i's one-hop neighbors which do not subscribe to channel c and have not obtained content d. Node k is j's one-hop neighbors which subscribe to channel c and have not obtained content d.
- We ignore node k's other one-hop neighbors.

Proposed Scheme ConDis - Buffer Manager

- Objective of nodes in the network:

$$Max\ \ U_i = \sum_{c=1}^{C}\Big(\sum_{d\in\theta(c)} U_i(d) - \sum_{d\in\phi(c)} U_i(d)\Big),$$

- U_i is the utility function of node i; C is the total number of channels; and $\theta(c)$ and $\phi(c)$ are the set of contents associated to channel c in their buffer after and before exchange, respectively.

Proposed Scheme ConDis

-Computing Content Utility

- Contact Probability Prediction: the pair-wise inter-contact time follows an exponential distribution.
  - PDF of the inter-contact time X_{ij} between nodes *i* and *j* can be expressed as:

$$f_{X_{ij}}(x) = \lambda_{ij} e^{-\lambda_{ij} x}. \qquad (8)$$

  - Then, the contact probability between nodes i and j within the remaining valid time Rd of content d can be expressed as:

$$Pr_{ij}(R_d) = Pr(X_{ij} \leq R_d) = \int_0^{R_d} f_{X_{ij}}(x)dx = 1 - e^{-\lambda_{ij} R_d}.$$

  - λ_{ij} is the contact rate between nodes *i* and *j*.

Proposed Scheme ConDis

-Computing Content Utility

- Expected Delay Prediction:
  - Based on Eq. (8), the expected delay Ed_{ij} for transmitting a certain content from node i to j can be calculated as:

$$ED_{ij} = E[X_{ij}] = \int_0^\infty x f_{X_{ij}}(x)dx = \frac{1}{\lambda_{ij}}.$$

  - the total time to transfer a content from i to k through j is $X^j_{ik} = X_{ij} + X_{jk}$, the PDF $f_{X^j_{ik}}(t)$ can be calculated as:

$$\begin{aligned} f_{X^j_{ik}}(x) &= f_{X_{ij}}(x) \otimes f_{X_{jk}}(x) \\ &= \lambda_{ij}\lambda_{jk} \int_0^x e^{-(\lambda_{ij}-\lambda_{jk})t} e^{-\lambda_{jk}t} dt \\ &= \frac{\lambda_{ij}\lambda_{jk}(e^{-\lambda_{ij}x} - e^{-\lambda_{jk}x})}{\lambda_{jk} - \lambda_{ij}}, \end{aligned} \quad (11)$$

  - $\otimes$ is the convolution operator

Proposed Scheme ConDis

-Computing Content Utility

- The expected delay Ed^{j}_{ik} for transmitting a certain content from *i* to *k* through *j* can be expressed as:

$$
\begin{aligned}
ED^{j}_{ik} &= E[X^{j}_{ik}] = \int_0^\infty x f_{X^{j}_{ik}}(x)dx \\
&= \int_0^\infty \frac{x\lambda_{ij}\lambda_{jk}(e^{-\lambda_{ij}x} - e^{-\lambda_{jk}x})}{\lambda_{jk} - \lambda_{ij}} dx \\
&= \frac{\lambda_{ij} + \lambda_{jk}}{\lambda_{ij}\lambda_{jk}}.
\end{aligned}
$$

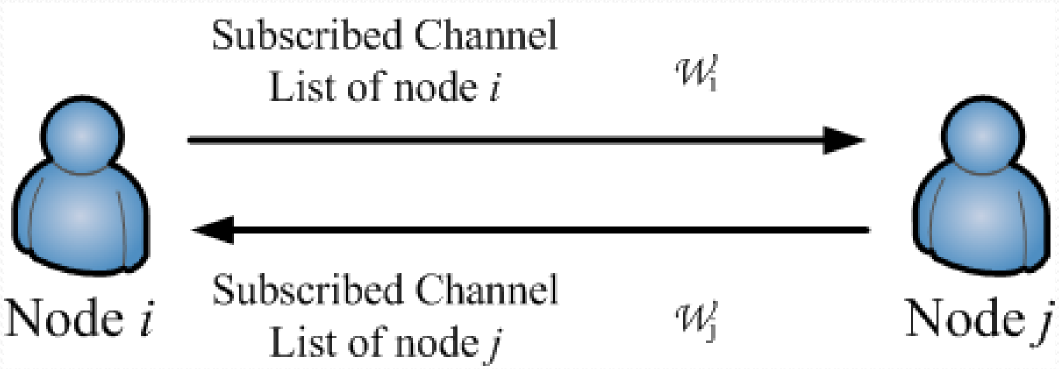
- Then, the content utility $U_i(d)$ of content *d* in channel *c* for node *i* can be expressed as follows:

$$
\begin{aligned}
U_i(d) &= w \sum_{j \in \mathcal{N}^1_i(c)} \frac{(R_d - \frac{1}{\lambda_{ij}})V}{T} \prod_{k \in \mathcal{L}^1_j(d)} e^{-\lambda_{jk}R_d} \\
&+ (1-w) \sum_{j \in \mathcal{M}^1_i(c)} \sum_{k \in \mathcal{N}^1_j(c)} \frac{(R_d - \frac{\lambda_{ij}+\lambda_{jk}}{\lambda_{ij}\lambda_{jk}})V}{T}.
\end{aligned}
$$

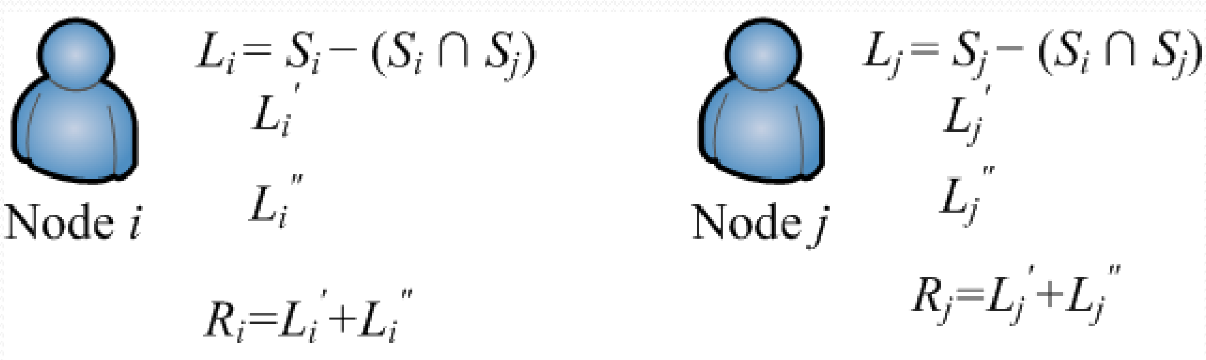
Proposed Scheme ConDis

-The Content Exchange Protocol

- Exchange control message, including subscribed channel list and collected buffer state of each other.

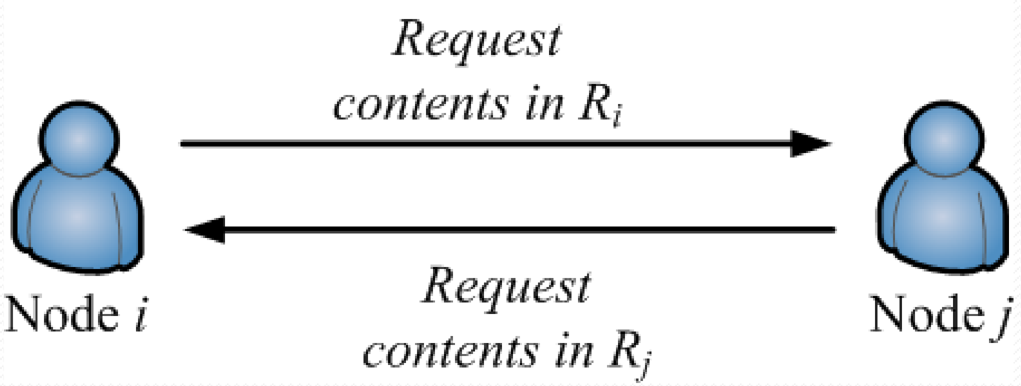


- Generate the candidate request list.



Proposed Scheme ConDis
-The Content Exchange Protocol

- Exchange content in the decreasing order of priority and content utility one by one.

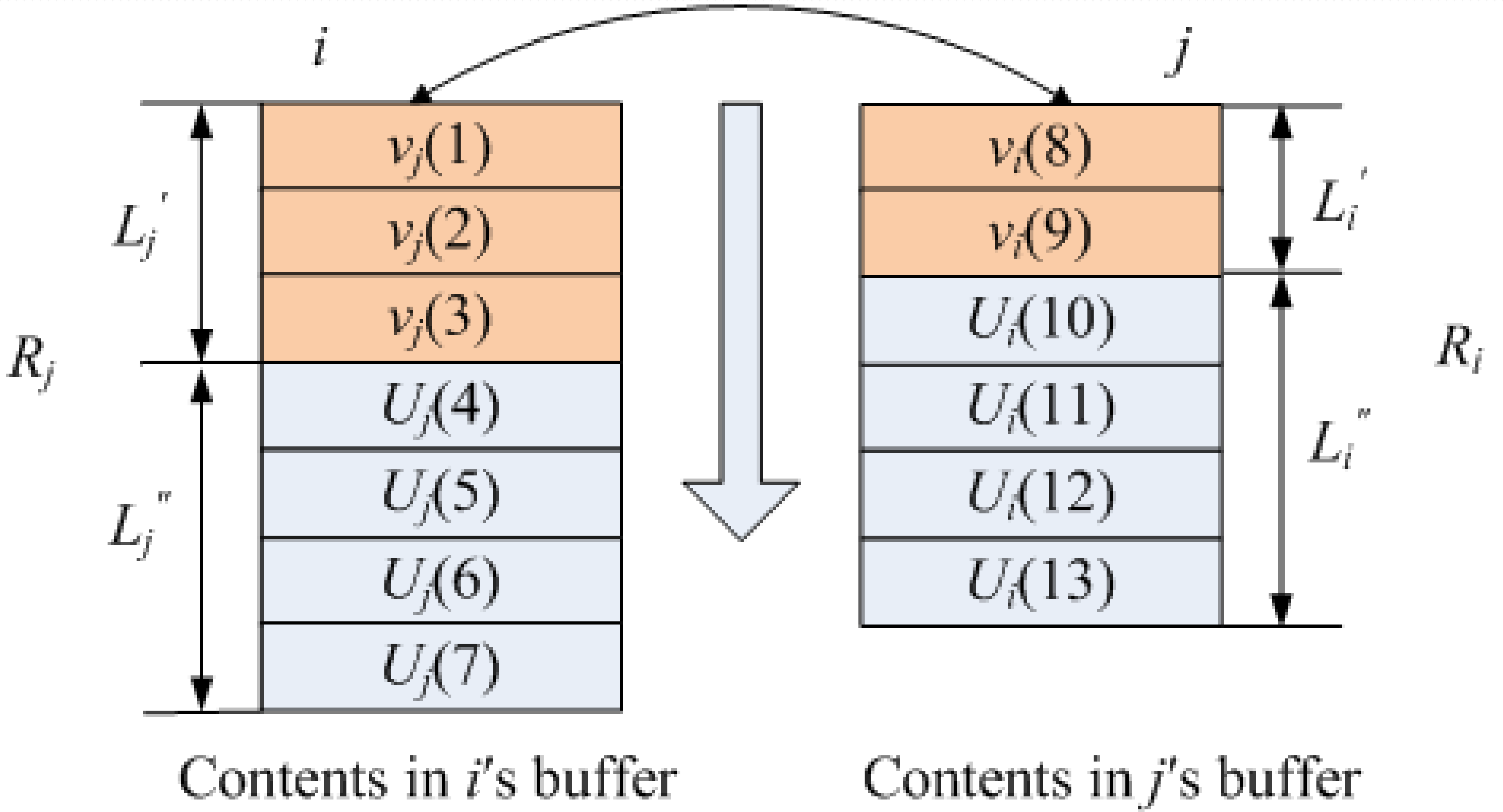


- Finish the trading until one side does not have contents, which can increase the total content utility in the buffer for the other side.

Proposed Scheme ConDis

-The Content Exchange Protocol

- An example about the content exchange process between nodes *i* and *j* in ConDis.



Outline

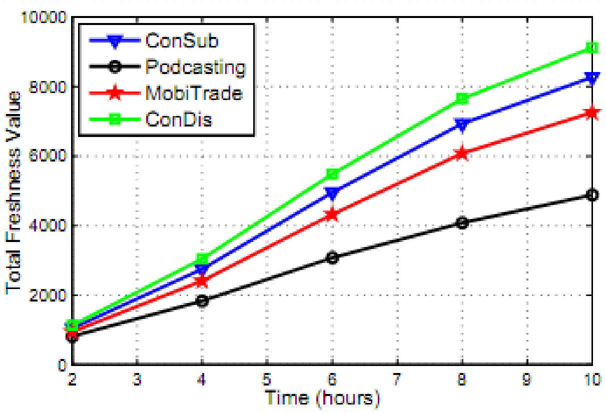
- Introduction
- Motivations
- Network Model
- Proposed Scheme ConDis
- **Performance Evaluation**
- Conclusion

Performance Evaluation

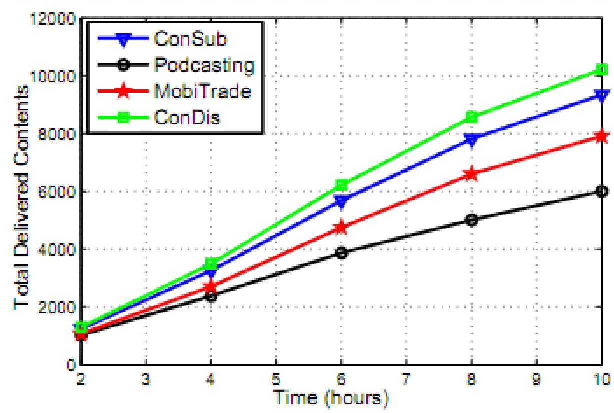
- We compare our work with Podcasting [17], MobiTrade [9], ConSub [8].
- Three Performance Metrics: Total freshness value, Total delivered contents and Total transmission Cost.
- Two experimental traces: Infocom 06 and MIT Reality.
- There are 5 channels in the network, and each node only expresses interest, randomly, in one channel.

Cont'd

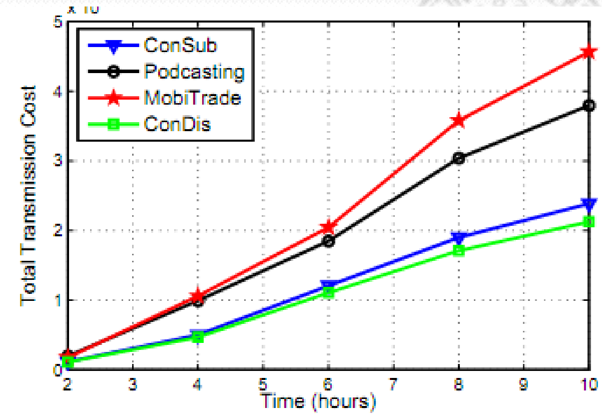
- Performance comparison



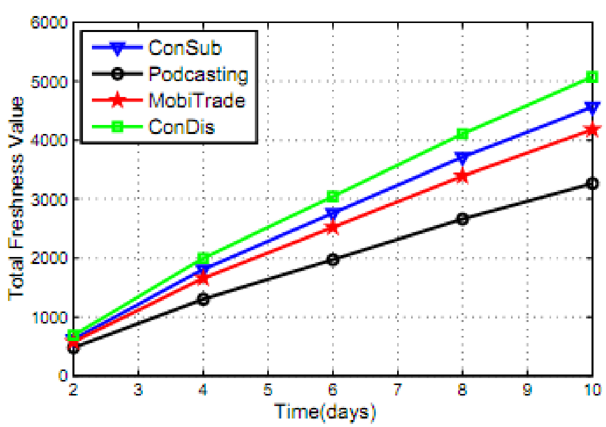
(a) Total Freshness Value



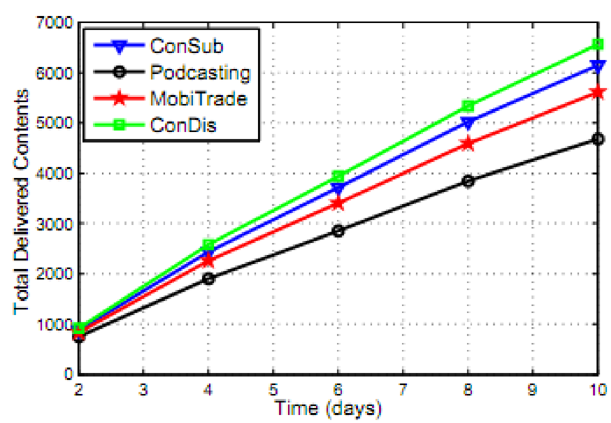
(b) Total Delivered Contents



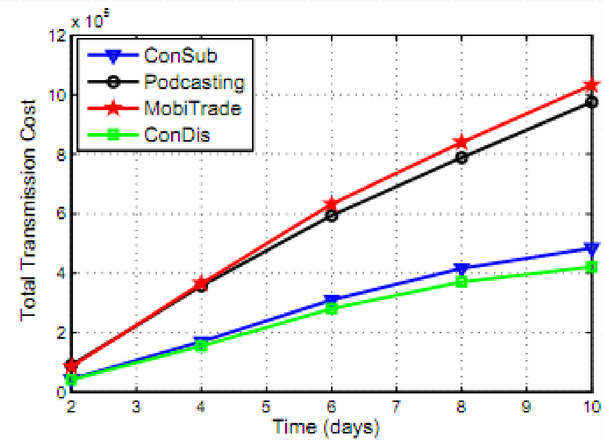
(c) Total Transmission Cost



(a) Total Freshness Value



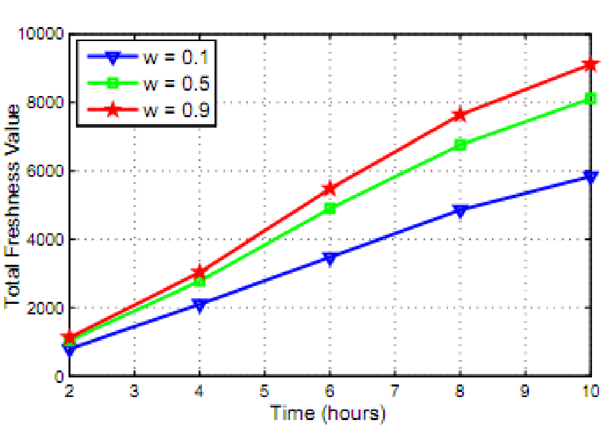
(b) Total Delivered Contents



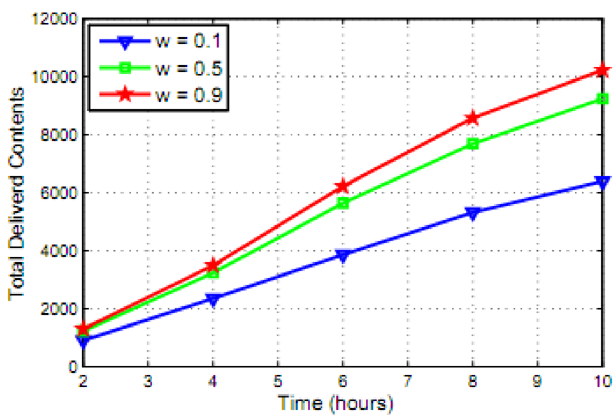
(c) Total Transmission Cost

Cont'd

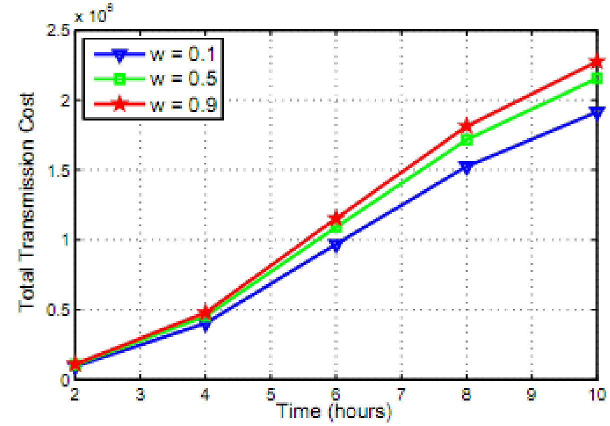
- Impact of w



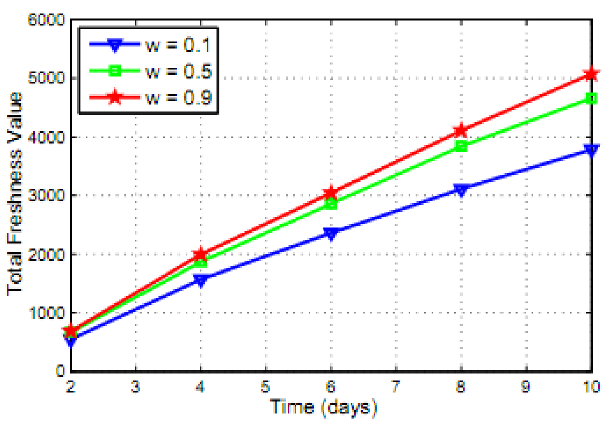
(a) Total Freshness Value



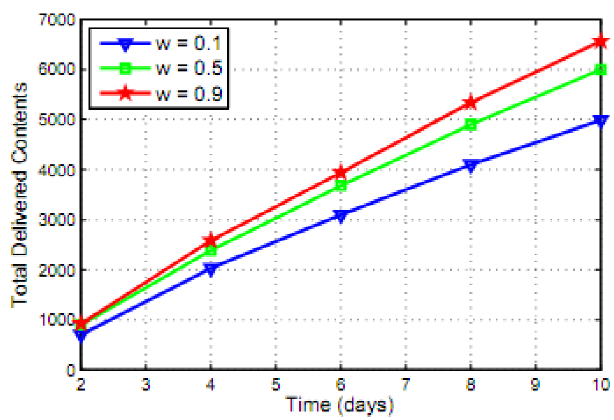
(b) Total Delivered Contents



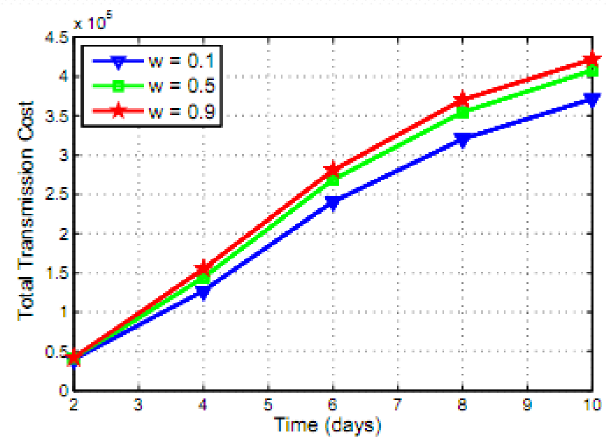
(c) Total Transmission Cost



(a) Total Freshness Value



(b) Total Delivered Contents



(c) Total Transmission Cost

Outline

- Introduction
- Motivations
- Network Model
- Proposed Scheme ConDis
- Performance Evaluation
- **Conclusion**

Conclusion

- We propose an incentive-driven and freshness-aware pub/sub content dissemination scheme, called ConDis, for selfish OppNets.
- we also propose a novel content exchange protocol when nodes are in contact.
- Extensive realistic trace-driven simulations are conducted to evaluate the performance of our proposed scheme

Thanks!

Questions?