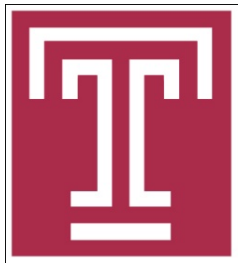
Mutually Exclusive Data Dissemination in the Mobile Publish/Subscribe System

Ning Wang and Jie Wu
Dept. of Computer and Info. Sciences
Temple University



Road Map

- Introduction
- Problem and challenge
- Centralized solution
- Distributed solution
- Experiments
- Conclusion and future work

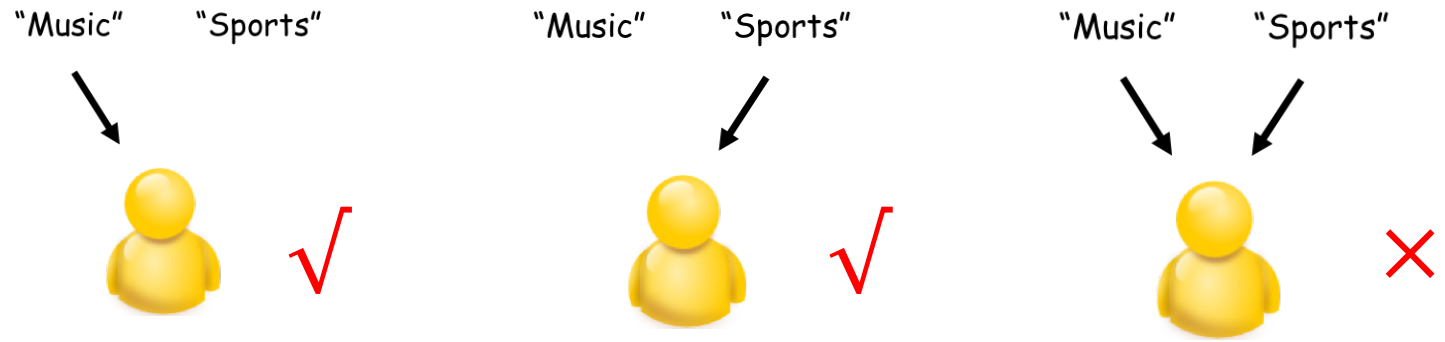
Introduction

- Data dissemination in Mobile Social Networks
  - Distributed system
    - Proximity-based communication, no cellular network
  - Pub/sub paradigm
    - Data are labeled with topics.
    - Mobile user identifies its interest topics (e.g., "Music" or "Computer Science") to filter data.
    - No specific destination set

- Application scenarios
  - Service advertising, news spreading, environmental alert

Introduction

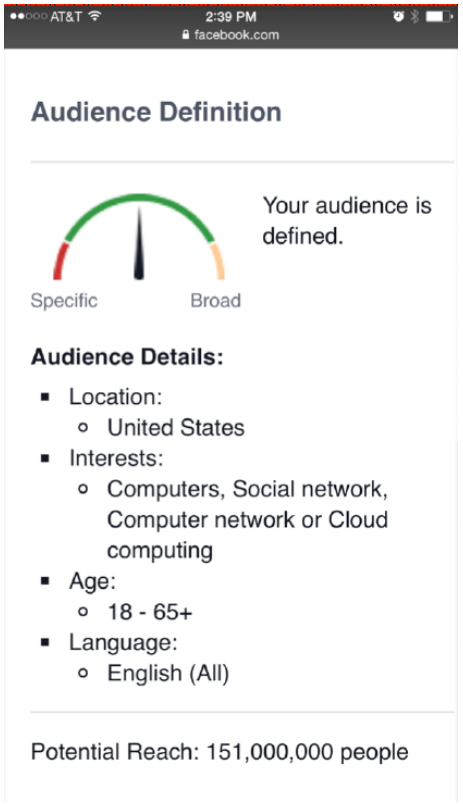
- Mutually exclusive data dissemination
  - A user might be interested in multiple topics, receiving anyone and only one is enough.



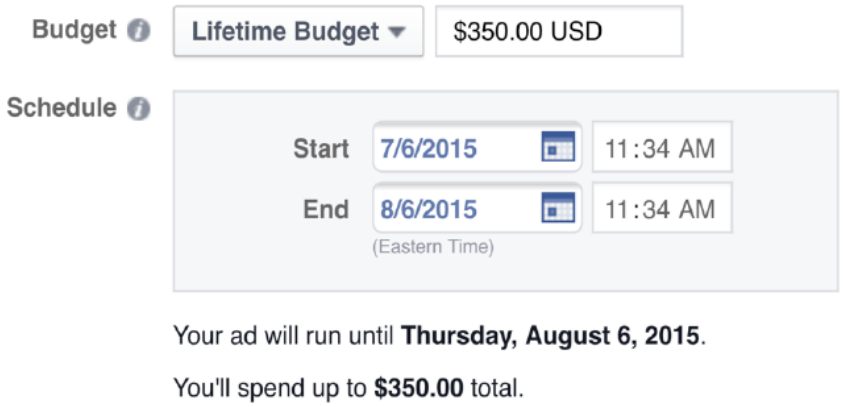
- Potential applications:
  - Digital ads (receiving too much will impact the user's experience.)
  - Electric coupon system (only apply one at checkout)
  - Carpool invitation (only choose one car)

Introduction

- A budget-constrained data dissemination
  - Data amount under each topic is pre-determined.
    - E.g., Facebook advertisement



Real example in facebook advertisement



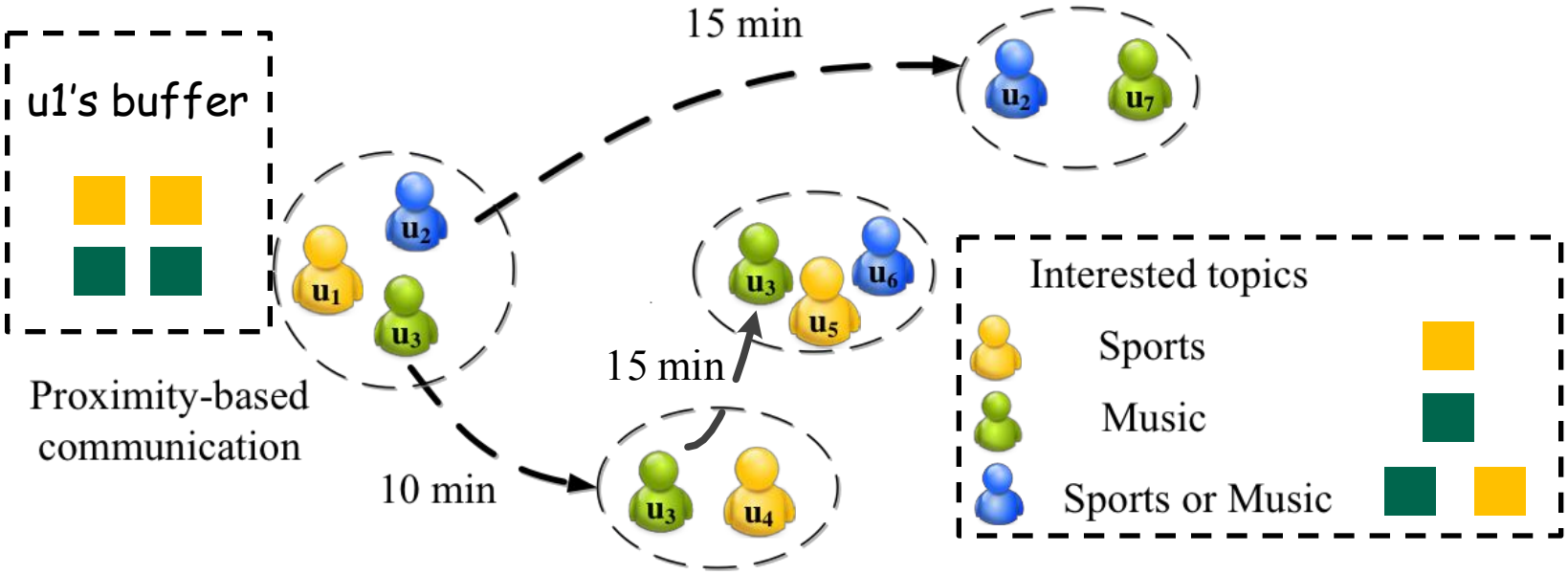
Problem and challenge

- Challenge
  - How to assign data to a node with multiple interest topics leads to a unique challenge.

- Problem
  - Given a pre-defined dissemination budget $\{n_1, n_2, \ldots, n_k\}$ in k topics, $\sum n_i = N$, and nodes' interest information in a mobile social network,
  - How to minimize the maximum data delivery delay with the mutually exclusive delivery requirement?

Problem and challenge

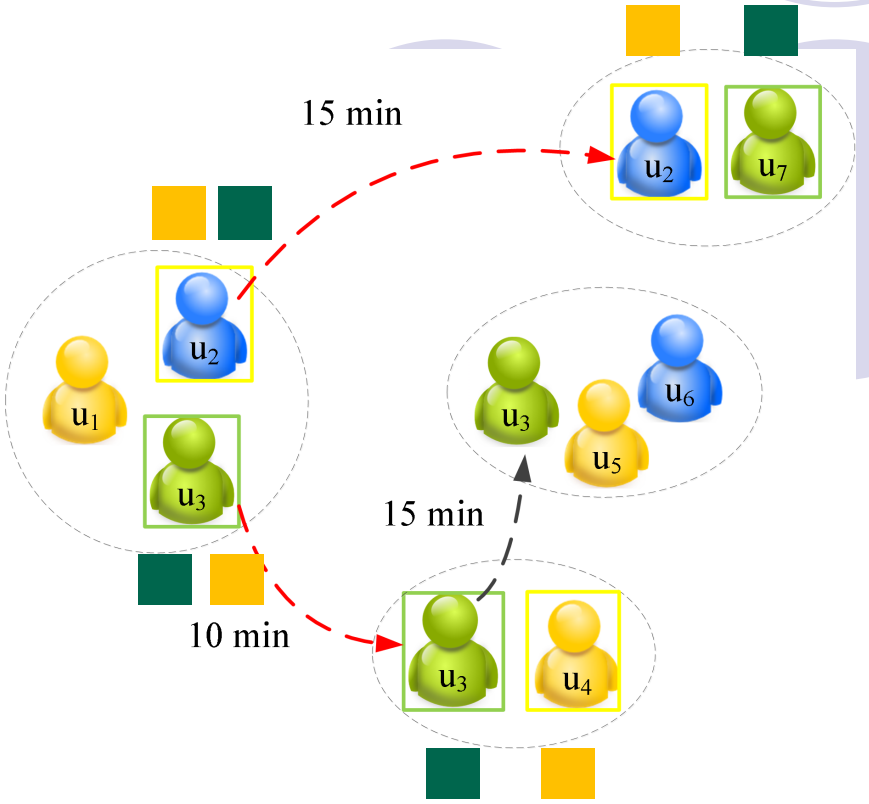
- Different data assignment leads to different forwarding delay.
  - A motivational example
    - u1 carries 4 data (2 "sports" , 2 "music")
    - Assign u2 , "sports" or "music"



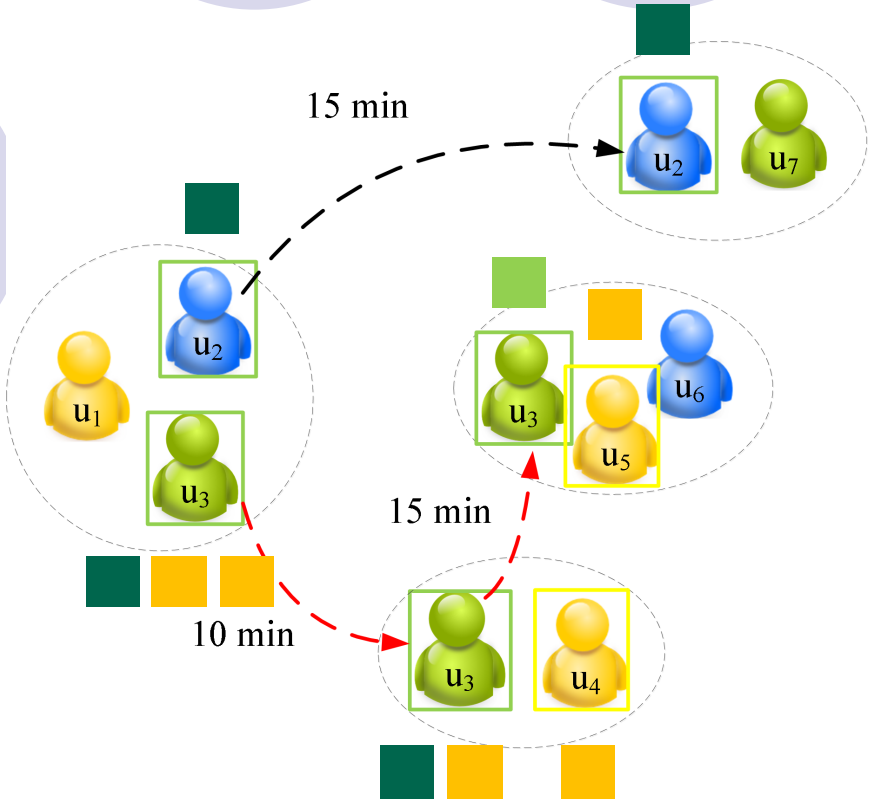
Problem and challenge

Different data assignment of u2

- Assign u2 "sports",
  - Optimal delay: 15 min



- Assign u2 "music",
  - Optimal delay: 25 min

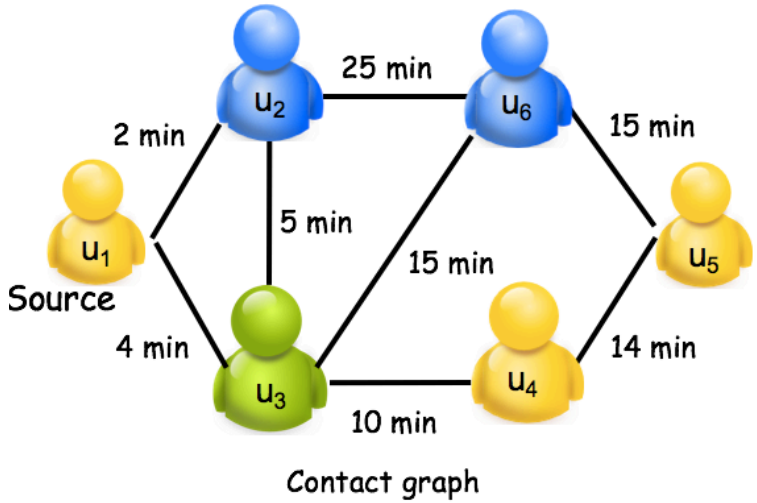


Centralized solution

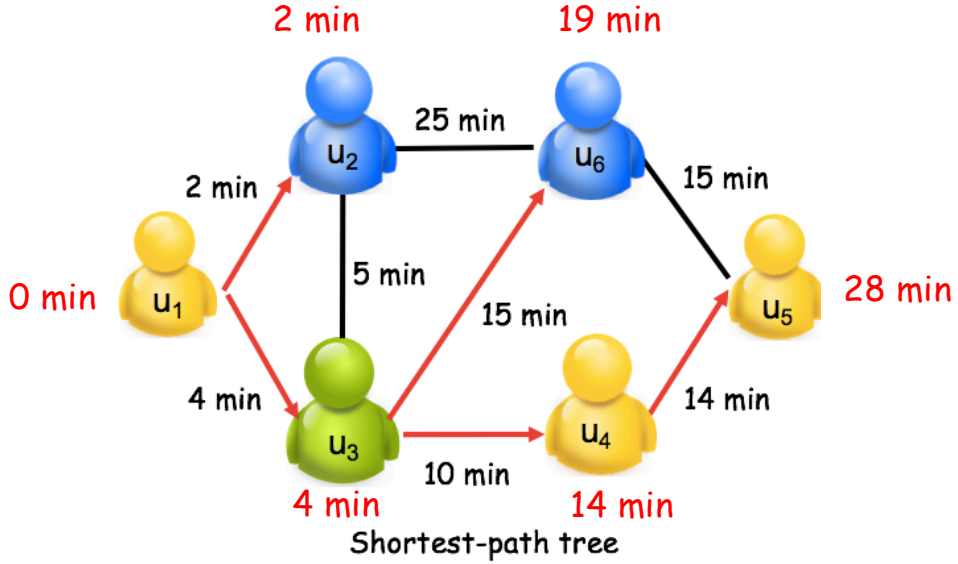
- The network topology and contact frequency between nodes are known.
  - Three sub-problems
    - How many reachable nodes are within time, T?
      - Shortest-path algorithm
    - Is there a feasible assignment within time, T?
      - Assignment problem (solved it this paper)
    - How to find the minimal T?
      - Binary search

Centralized solution

- How many reachable nodes are within time, T?
  - Build the shortest-path tree from source node algorithm in the contact graph, the number in the edge is the average contact interval.



Contact graph



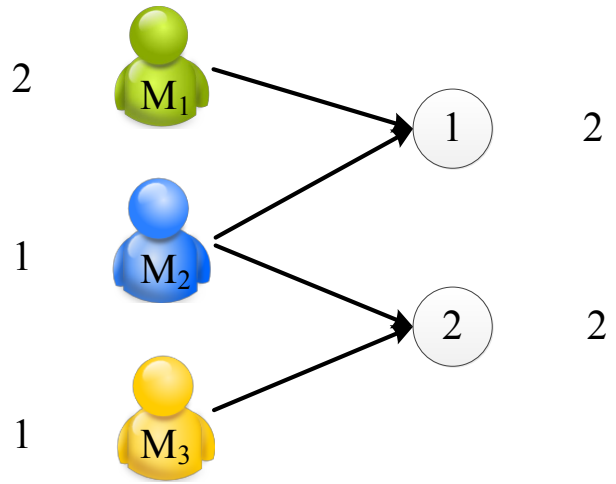
Shortest-path tree

  - Build a table based on the reachable time

Reach time (min)	0	2	4	14	19	28
Node ID	1	2	3	4	6	5

Centralized solution

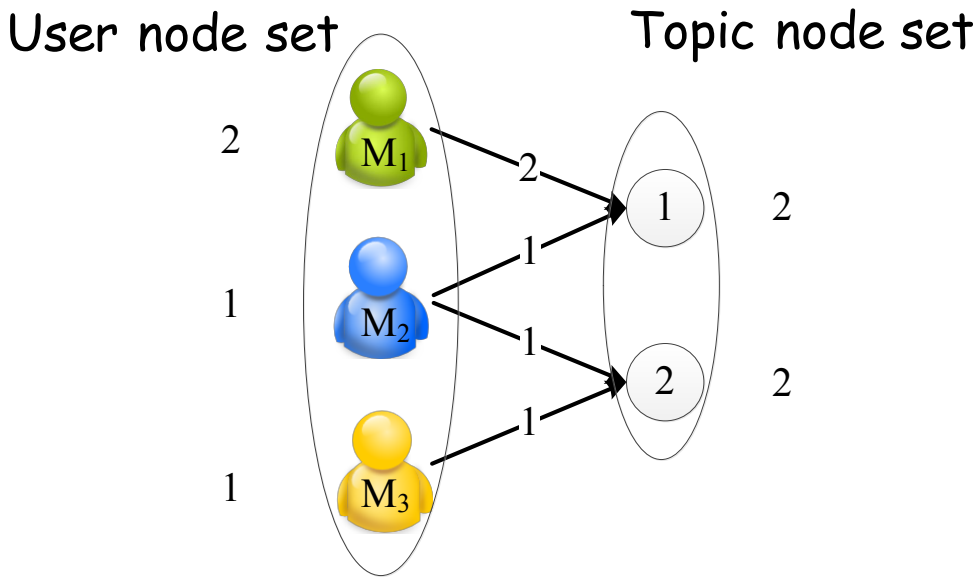
- Assignment problem
  - Is there a feasible assignment in T?
    - An assignment with mutually exclusive delivery requirement between different types of user and different topics
- An example



Number of mobile user in each type topic budget

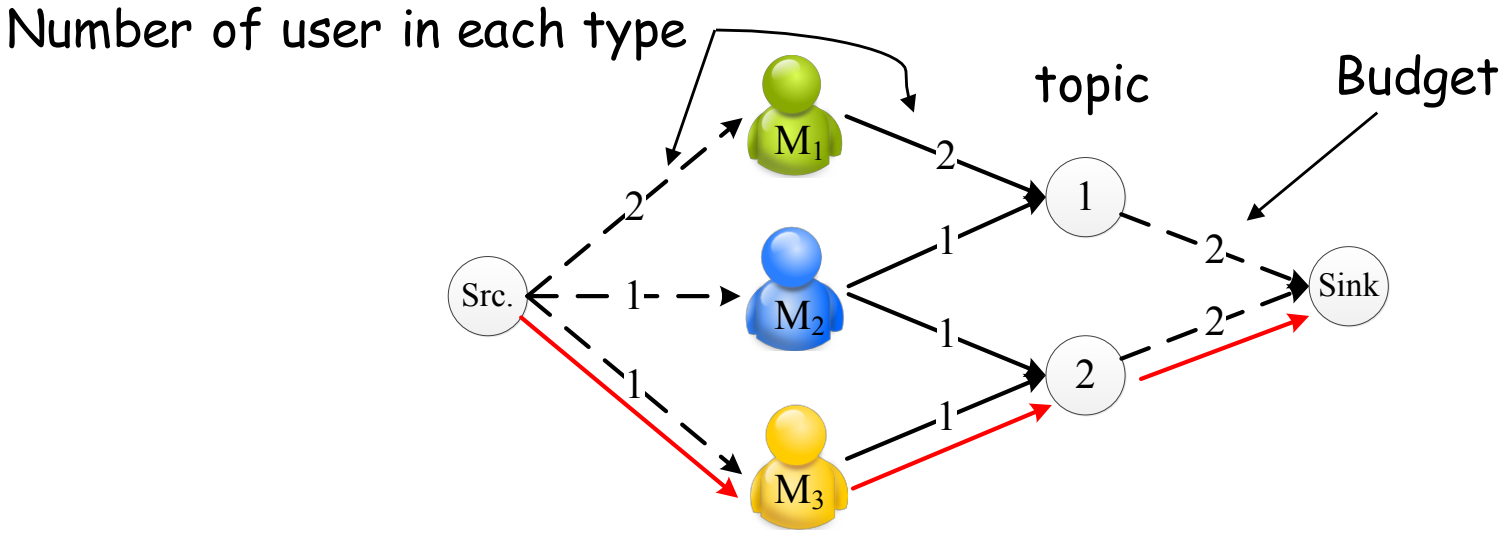
Centralized solution

- Max-flow formulation
  - Two sets of nodes
    - Mobile user node set and the topic set
  - Each type of user has connection to its interests
    - The capacity from the user node to its interested topic is the amount of each type of mobile user.



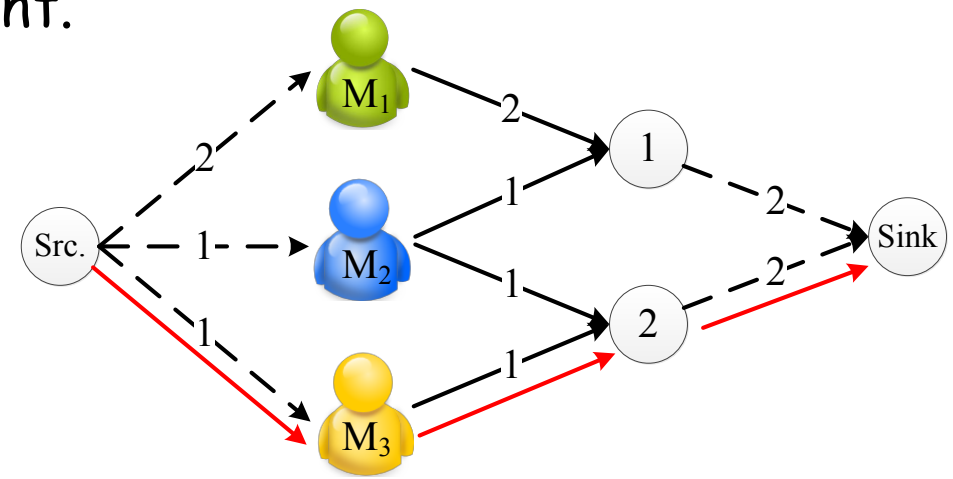
Centralized solution

- Max-flow formulation
  - Add virtual source and sink
    - The capacity from source to each type of user equals to each type of user to topic.
    - The capacity from each topic node to sink equals to the budget in each topic.



Centralized solution

- Max-flow formulation
  - Correctness
    - Mutually exclusive delivery requirement: each user can be assigned at most once.
      - source link capacity = user node to topic node capacity
    - Feasibility: A max-flow will consume all the capacity from the topic nodes to sink. Finishing all the assignment.



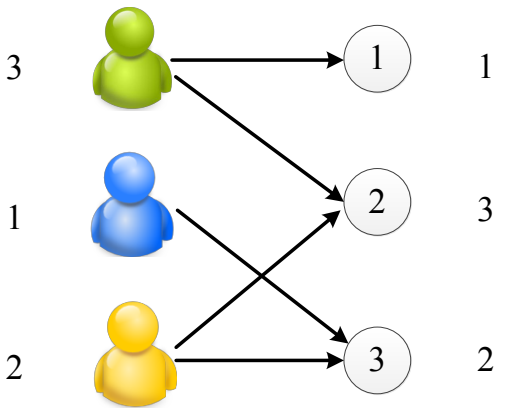
Centralized solution

- Greedy algorithm
  - Further reduce the algorithm complexity

- A simple idea
  - If the data amount under a topic is close to the number of users which can consume it, this type of data should be assigned to the user first, otherwise, later, it might not be able to find enough user to consume it.

Centralized solution

- Most-unbalanced-first algorithm
  - Three definition (from the topic side)
    - Supply level of topic i:
      - Remaining amount of data in topic i
    - Consumption level of topic i:
      - Remaining amount of mobile users which subscribe topic i
    - Unbalance level of topic i:
      - Difference between the consumption level and supply level of topic i

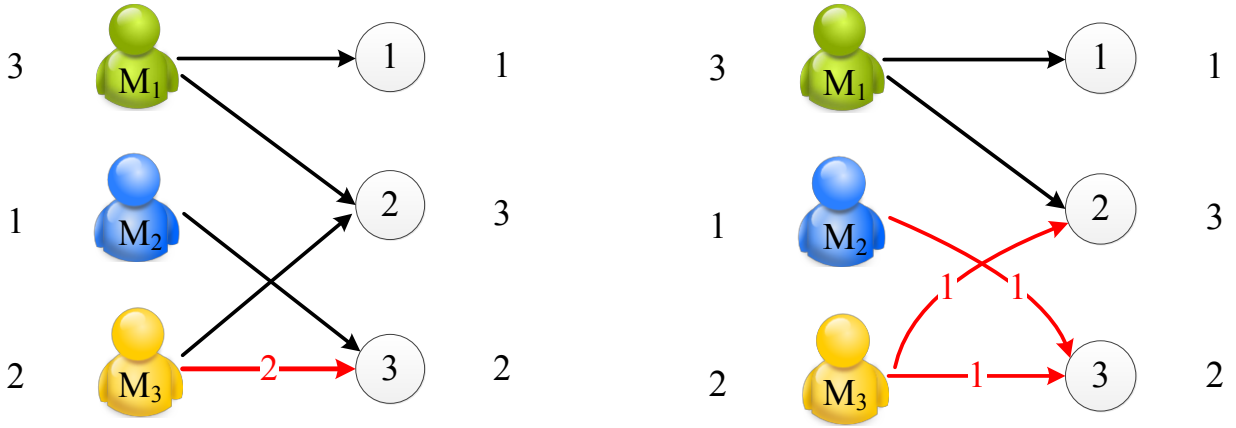


Topic	Supply	Consumption	Unbalance
1	1	3	2
2	3	5	2
3	2	3	1

√

Centralized solution

- Node's interest amount matters
  - An example
    - The unbalance level for three topics is 2, 2, 1, respectively.
      - Topic 3 is the most unbalanced.
        - We can assign user in M_2 or M_3 to consume data in topic 3 first.



Assign M_3 first, M_2 cannot be further assigned

Assign M_2 first

- M_2 mobile user has only one choice, should have higher priority!

Centralized solution

- Greedy_plus algorithm
  - Jointly consider from the user and topic (two sides)
  - While we can do data assignment
    - Find the set of mobile users with the fewest topic.
    - The most unbalanced topic is assigned from the selected set of mobile users.

Theorem: if each mobile user subscribes at most two topics, the user assignment amount of greedy_plus algorithm is maximum.

Insight: maximize the the assignment feasibility from two sides

Distributed scenario

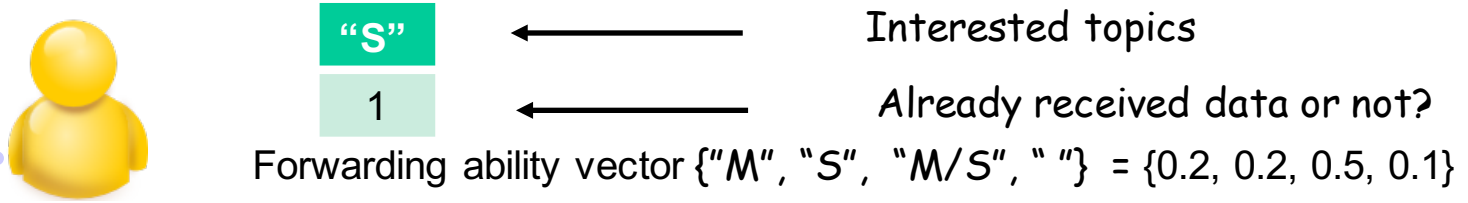
- The network topology and contact frequency between nodes are unknown.

- Two main challenges
  - Forwarding ability estimation
    - How many data copy and which type of data copy should be forwarded to the encountered node?
  - Local data assignment
    - For the encountered node with multiple interests, which type of data should the encountered node consume?

Distributed scenario

- Forwarding ability estimation
  - Nodes record and exchange their interest information with neighbors to get the network estimation for different topics overtime.

  - An illustration
    - Two topics, "M" and "S" in the network
      - 4 different type of users {"M", "S", "M/S", " "}.
      - If the encountering probability of a node to these four different type nodes are {0.2, 0.2, 0.5, 0.1}, its forwarding ability vector is V = {0.2, 0.2, 0.5, 0.1}.



Distributed scenario

- Local data assignment
  - Encountering node with single interest

Buffer	"S"	"M"
Amount	9	12

"S"
1

encountering ⟷

Buffer	"S"	"M"
Amount	0	0

"S"
0

V1 {"M", "S", "M/S", " " } = {0.7, 0.1, 0.1, 0.1} V2 {"M", "S", "M/S", " " } = {0.5, 0.3, 0.1, 0.1}

Average forwarding ability {0.6, 0.2, 0.1, 0.1}

Direct data consumption

Buffer	"S"	"M"
Amount	8	12

"S"
1

encountering ⟷

Buffer	"S"	"M"
Amount	0	0

"S"
1

Data copy splitting (proportional to V1/(V1 + V2) and V2/(V1 + V2)):

The expected delay for "M" 12/0.6 = 20 smaller than "S" 8/0.2 = 40, therefore, we will regard the utility of "M/S" nodes as utility of "S" nodes

Buffer	"S"	"M"
Amount	3	7

"S"
1

encountering ⟷

Buffer	"S"	"M"
Amount	5	5

"S"
1

Distributed scenario

- Local data assignment
  - Encountering node with multiple interest

Buffer	"S"	"M"
Amount	9	12

"S"
1

encountering

Buffer	"S"	"M"
Amount	0	0

"S"	"M"
0	0

V1 {"M", "S", "M/S", " " } = {0.7, 0.1, 0.1, 0.1} V2 {"M", "S", "M/S", " " } = {0.5, 0.3, 0.1, 0.1}

Average forwarding ability {0.6, 0.2, 0.1, 0.1}

  - Direct data consumption (min-max volume algorithm)
    - Consume the data with the largest amount.

Buffer	"S"	"M"
Amount	9	11

"S"
1

encountering

Buffer	"S"	"M"
Amount	0	0

"S"	"M"
0	1

  - Data copy splitting (proportional splitting):

Buffer	"S"	"M"
Amount	3	6

"S"
1

encountering

Buffer	"S"	"M"
Amount	6	5

"S"	"M"
0	1

Distributed scenario

- Local data assignment
  - Encountering node with multiple interest
  - Min-max speed algorithm
    - Increase the data delivery delay in the slowest topic as much as possible.
  - To minimize the maximum data delivery delay, the bottleneck is the lowest delivery delay of a topic.
    - Walter-filling condition

Theorem: if different types of mobile users are uniformly distributed in the network, a schedule which makes max ratio between data budget and the amount of interested users in any topic minimized, it is the optimal assignment.

Distributed scenario

- Local data assignment
  - An example of the min-max speed algorithm

Buffer	"S"	"M"
Amount	9	12

"S"
1

encountering

Buffer	"S"	"M"
Amount	0	0

"S"	"M"
0	0

V1 {"M", "S", "M/S", " " } = {0.7, 0.1, 0.1, 0.1} V2 {"M", "S", "M/S", " " } = {0.5, 0.3, 0.1, 0.1}

Average forwarding ability {0.6, 0.2, 0.1, 0.1}

  - Direct data consumption:
  - The expected delay for "M" 12/0.6 = 20 smaller than "S" 9/(0.2 + 0.1) = 30, even we regard all "M/S" nodes s as "S" nodes , therefore, we will consume "S" data to increase its delivery speed.

Buffer	"S"	"M"
Amount	8	12

"S"
1

encountering

Buffer	"S"	"M"
Amount	0	0

"S"	"M"
1	0

Data copy splitting (proportional splitting):

Buffer	"S"	"M"
Amount	3	7

"S"
1

encountering

Buffer	"S"	"M"
Amount	5	5

"S"	"M"
1	0

Distributed scenario

- Forwarding ability estimation (an extension)
  - Record whether a user is interested in a topic
    - For example, if we have two topics, "M" and "S" in total, the forwarding ability vector will be like {0.4, 0.6}.
      - Advantage: reduce the forwarding utility vector attributes.
      - Disadvantage: Do not have the estimation for nodes with multiple interests
  - Positive estimation
    - Meeting a user with n interests regards as meeting n users with single interest in utility calculation.
  - Negative estimation
    - Meeting a user with n interests regards as meeting 1/n users with single interest in utility calculation.

Experiments

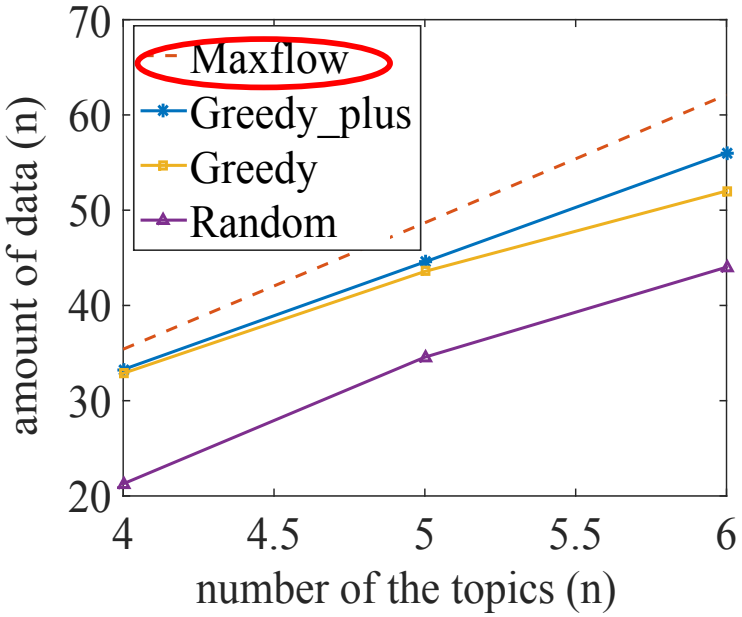
- Trace setting:
  - Synthetic trace
    - 100 nodes, 60000 contacts
      - Randomly contact, average contact frequency 1s
      - Each node randomly has 2 – 6 different topics
      - Average subscription number for a topic 20 to 40
      - Data budget, 20 to 80
  - INFOCOM 06 trace
    - 78 nodes, 227657 contacts
      - Questionnaire to get the user's interests
      - with 35 different topics
      - Average subscription number for a topic is 12
      - Data budget, 10 to 40

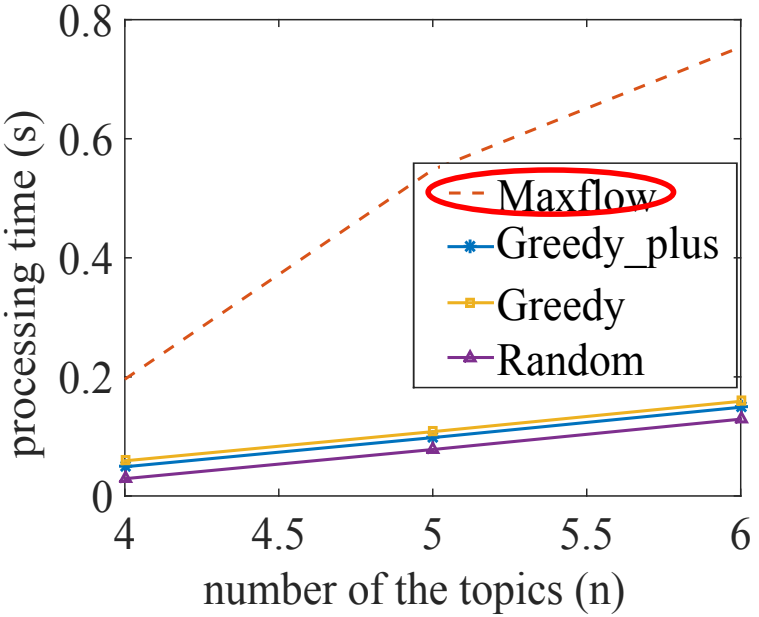
Experiments

- Algorithm comparison:
  - Centralized algorithm
    - Max-flow: proposed max-flow data assignment
    - Greedy_plus: proposed modified greedy algorithm
    - Greedy: most-unbalanced-first algorithm
    - Random: randomly assign data
  - Distributed algorithm
    - Min-max speed: proposed data assignment
    - Min-max volume: same as min-max speed, instead of assigning the node with multiple data with data with the largest amount.
    - Random: random assignment

Experiments

- Centralized environment
  - Performance of centralized data assignment algorithms in synthetic trace
  - Randomly generate users' interests and data budget, compare the average data delivered number of user in time 100 seconds.



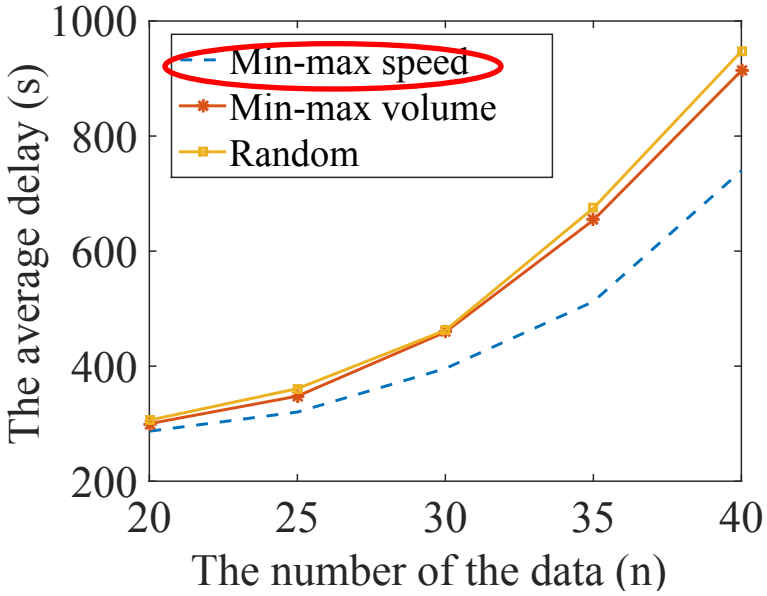


  - Max-flow algorithm achieves the best performance with max processing time. The Greedy2 algorithm improves performance with a low processing time.

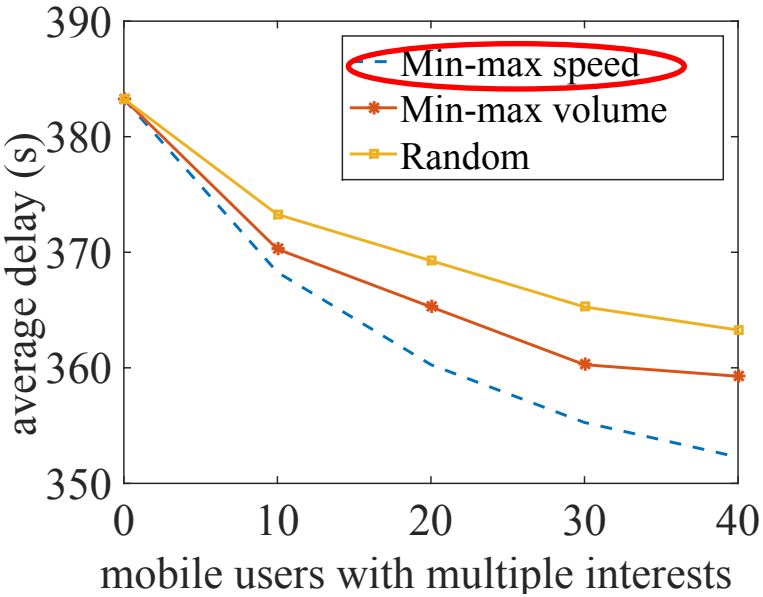
Experiments

- Distributed environment
  - Performance of distributed data assignment in synthetic trace

Given the total budget, random generation data budget in different topics



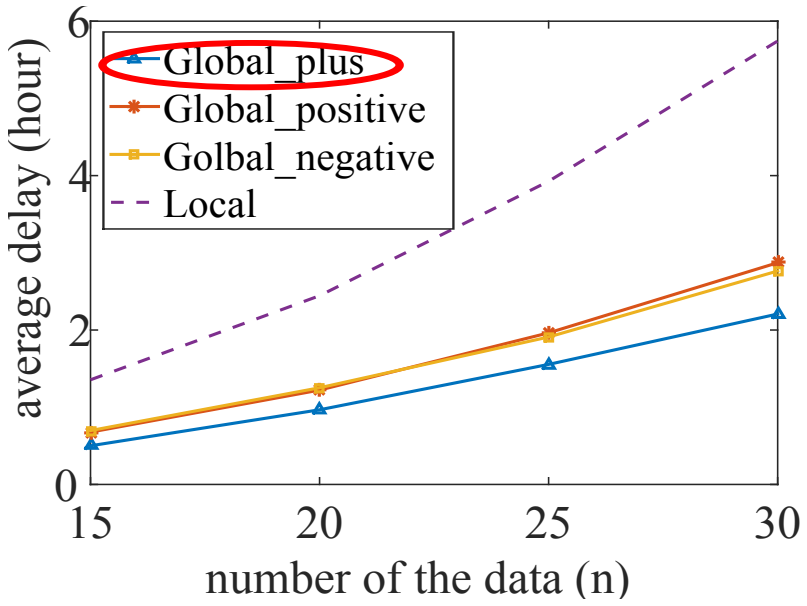
Given the budget assignment, random generation node's interests



  - The proposed min-max speed algorithm balances the data delivery speed in different topics, therefore, the maximum delay is minimized.

Experiments

- Distributed environment
  - Performance of the different utility estimation in INFOCOM trace
    - 2 different topics are randomly selected from 35 topics
      - Single source, random data budget in different topics.
    - Compare the min-max speed algorithm in different utility estimation methods



The total data budget

Global_plus:
vector of each type of user + vector exchange
Global_positive:
vector of each type of topic + vector exchange
Global_negative:
vector of each type of topic + vector exchange
Local:
vector of each type of user

- The proposed global estimation is the most effective approach.
  The positive/negative estimation is better than local estimation.

Conclusions

Proposed the Mutually exclusive data dissemination

Unique data consumption selection problem for a node with multiple interest

- Centralized solution
  - Max-flow formulation
- Distributed solution
  - Local data assignment selection
    - Water-filling condition
  - Distributed utility estimation

- Thanks!

- ning.wang@temple.edu
- jiewu@temple.edu