On the broadcast of segmented messages in dynamic networks

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Outline

1) Problem definition
2) Setup
3) Algorithms of Message Transfer
4) Deeper analysis of the algorithms
5) Conclusions

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Problem Definition

- Consider a dynamic and a distributed system of agents
- Connections between any pair of agents are intermittent
- Information dissemination occurs through epidemic protocols due to its dynamic nature
- A piece of information can be passed on when two nodes meet (i.e., establish communication link)

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- But what if the information is too large to be sent over in a single contact?

Split the Message

- A simple solution is to split the message into packets
- Hence, during a communication opportunity transfer only a part of the message
- But, how will message splitting influence the speed of dissemination?
- Will the underlying topology have any effect?
- Will it be possible to control resource wastage by devising efficient message spreading policy, especially, in a distributed environment?

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- Will it be possible to control resource wastage by devising efficient message spreading policy, especially, in a distributed environment?
- We consider the case of broadcast and try to answer these questions
- We also propose an efficient broadcast algorithm

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Agent and Message Configuration

- Agent configuration
  - A graph G=(V,E) represents a dynamic network
    - A node in V ➔ an agent, and
    - An edge in E ➔ a possible link between a pair of agents
    - In case, a link is not available at a particular time due to dynamic nature of the network, the link is considered as existing but inactive at that time

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- Message configuration
  - A message is split into a set of m packets and the packets are grouped into s segments, s.t., *m mod s = 0*

A message

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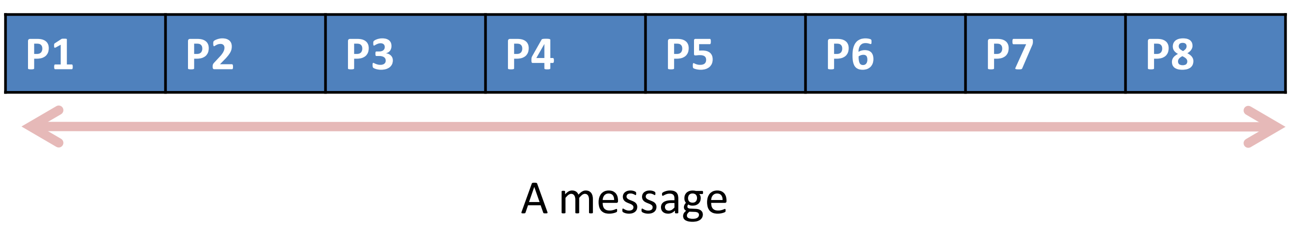

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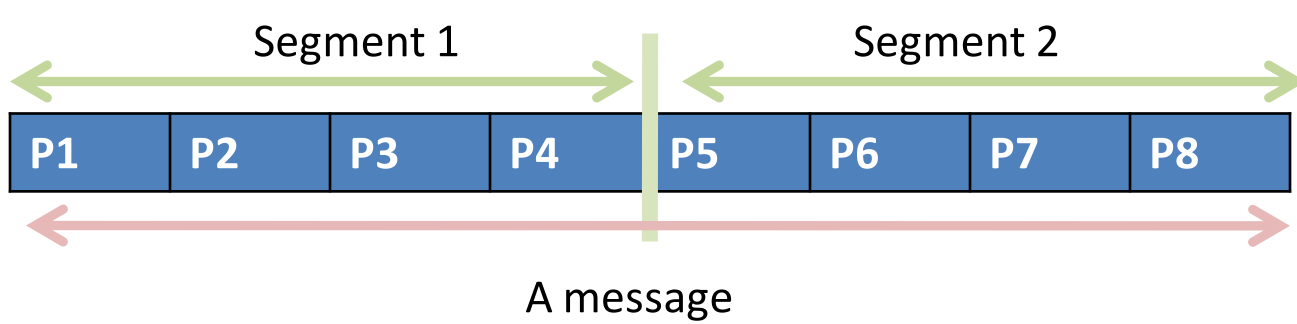
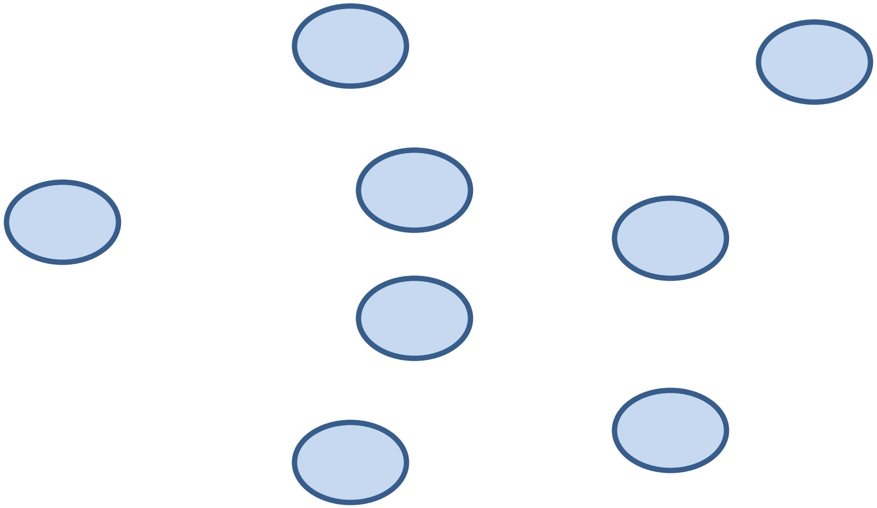


Dynamic Network Topology

- Topology specifies potential neighbors for each node
- At each time step, a node tries to connect with one of the neighbors selected randomly



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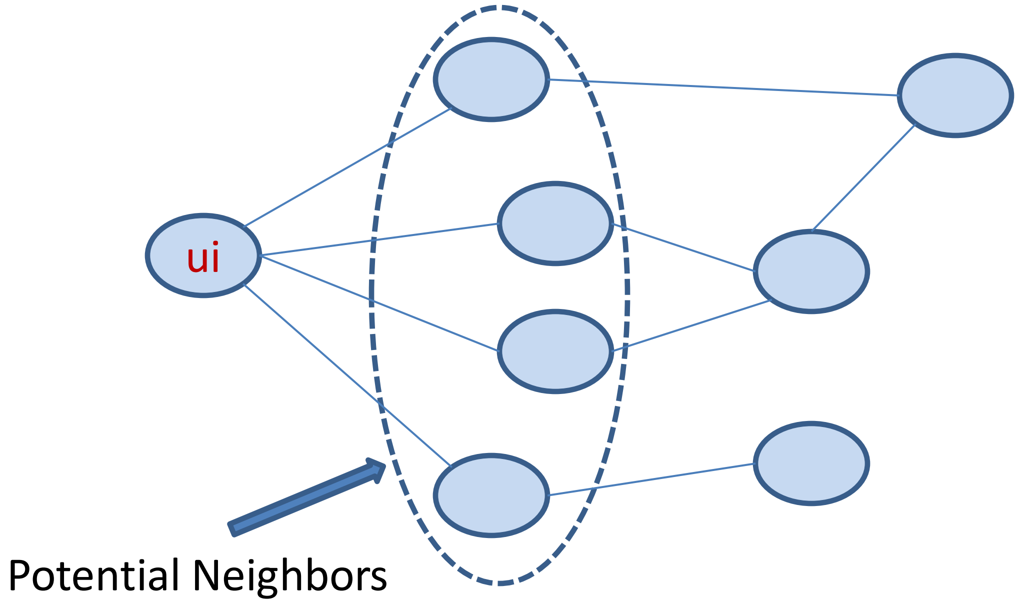

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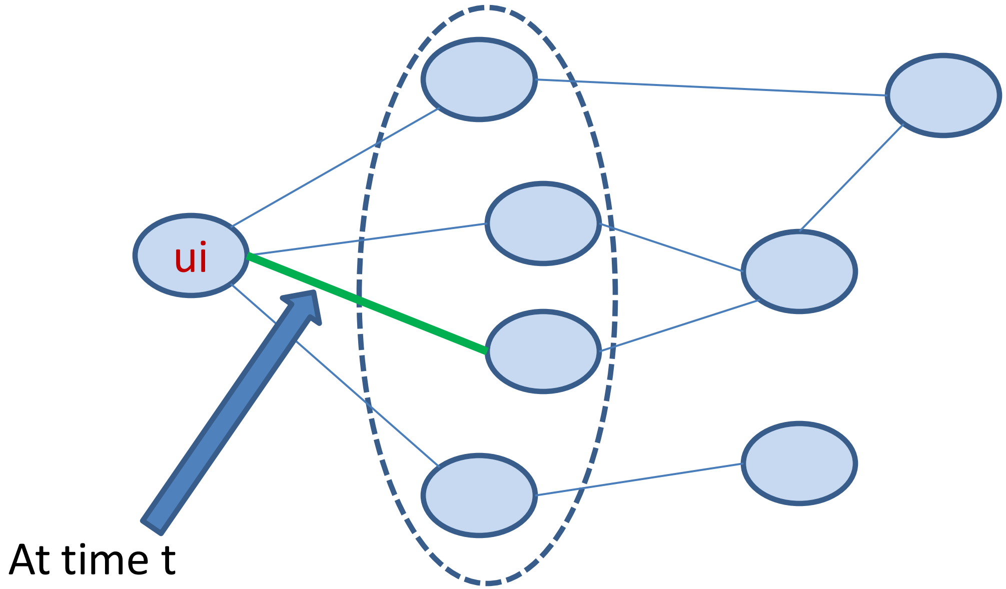

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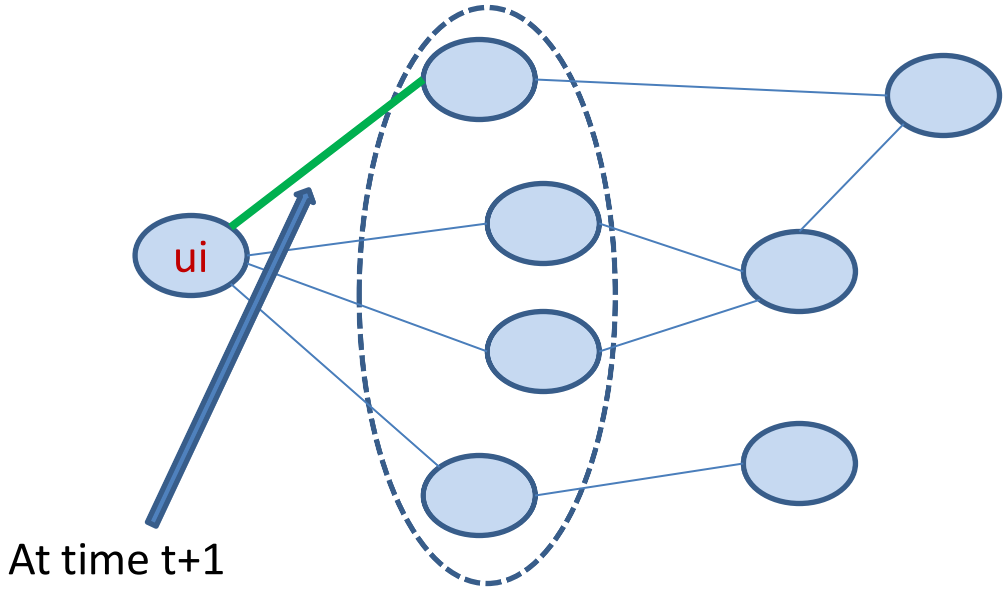
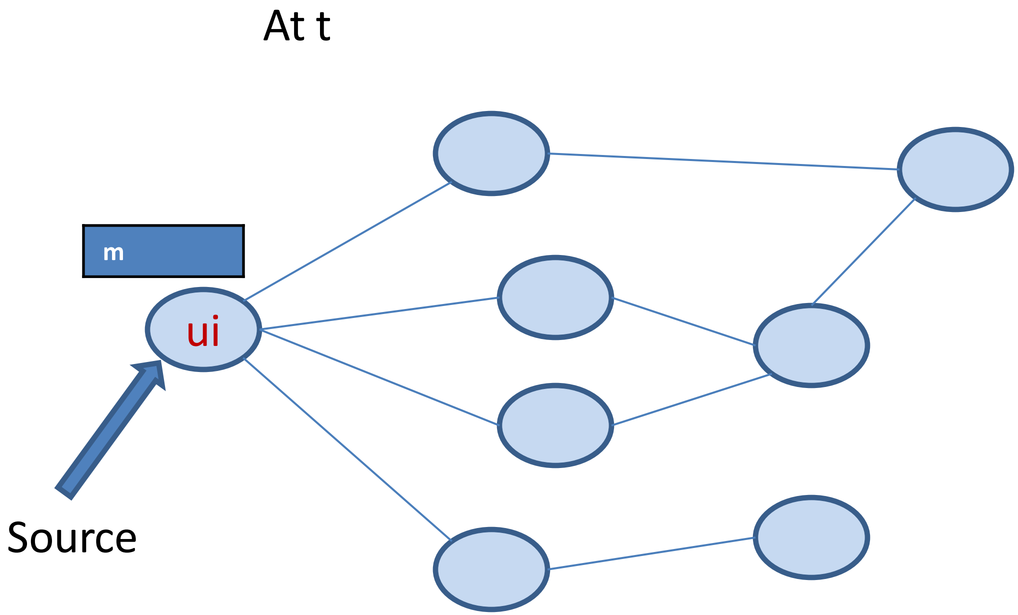


Transfer Protocols

- Consider a node as a sender when it has all the packets of a message
  - Initially, source is the only sender having all the packets
- And, the other nodes as non-senders that has no or not all packets of the message
  - Hence, non-senders won't start forwarding any packet
  - They do forward only when they become sender
- Two basic forwarding techniques
  - Push technique
  - Pull technique

Push Technique



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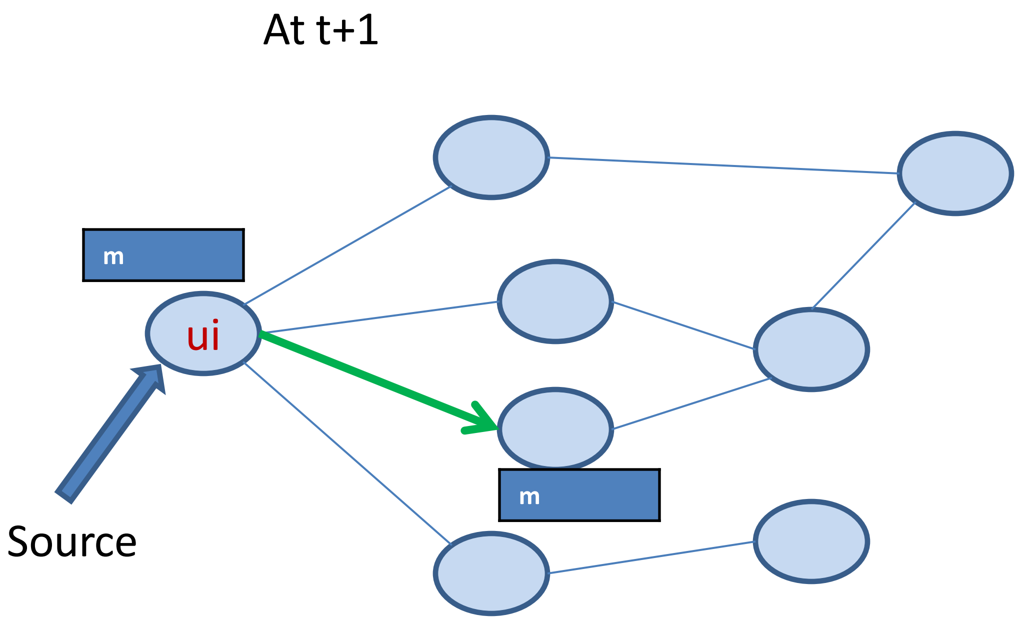

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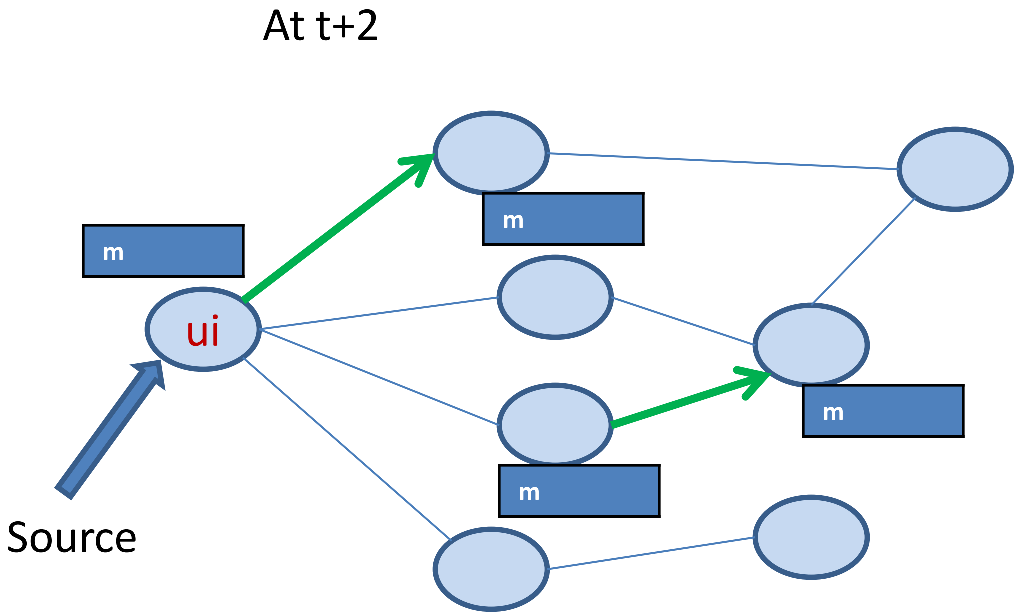

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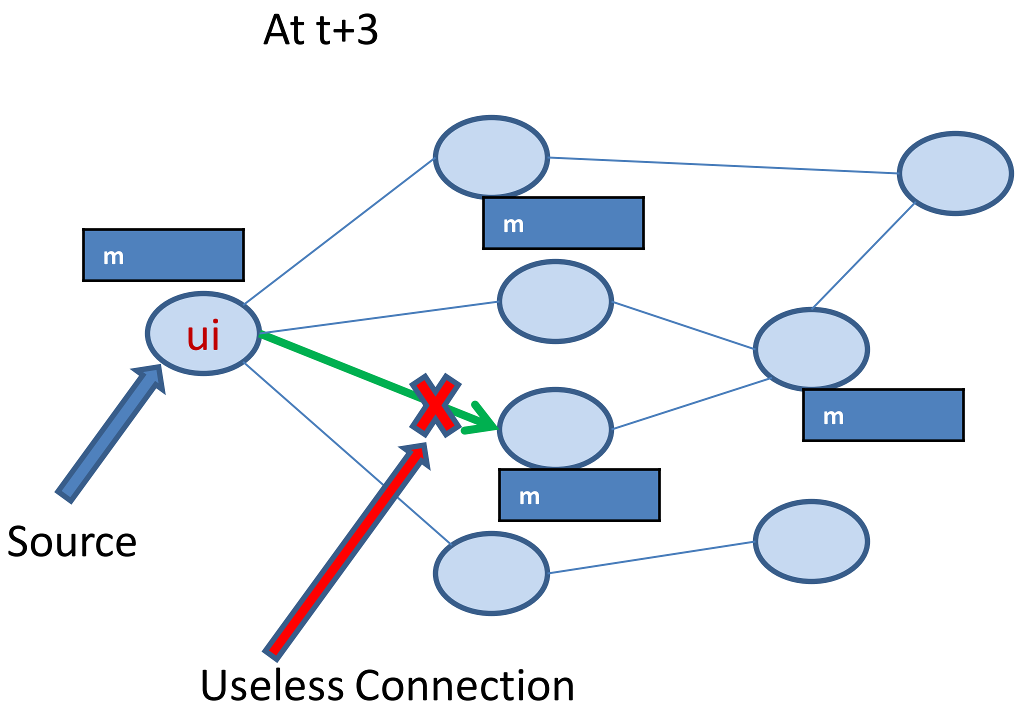

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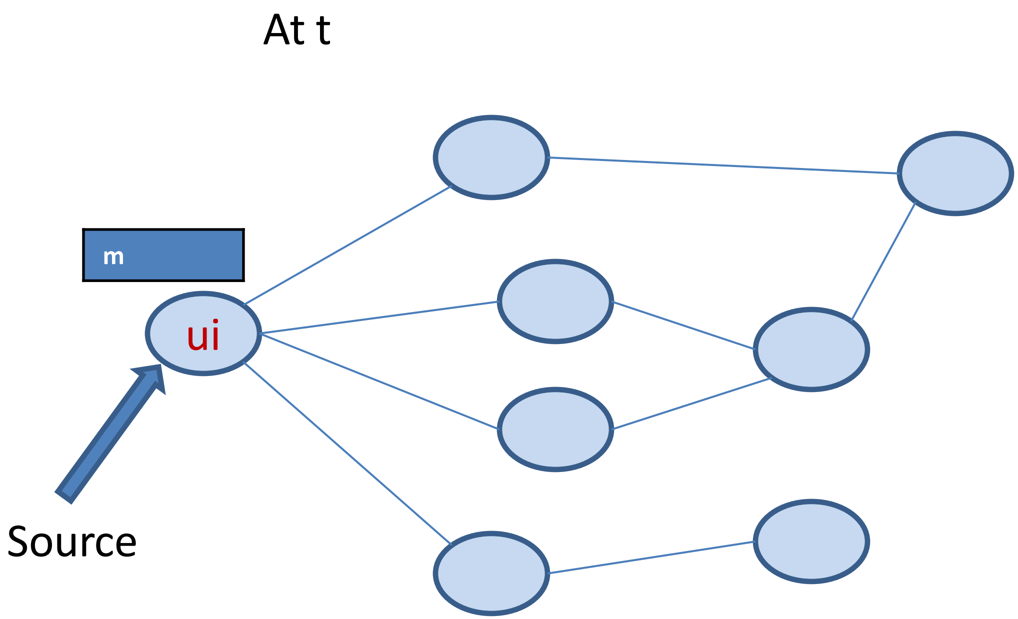

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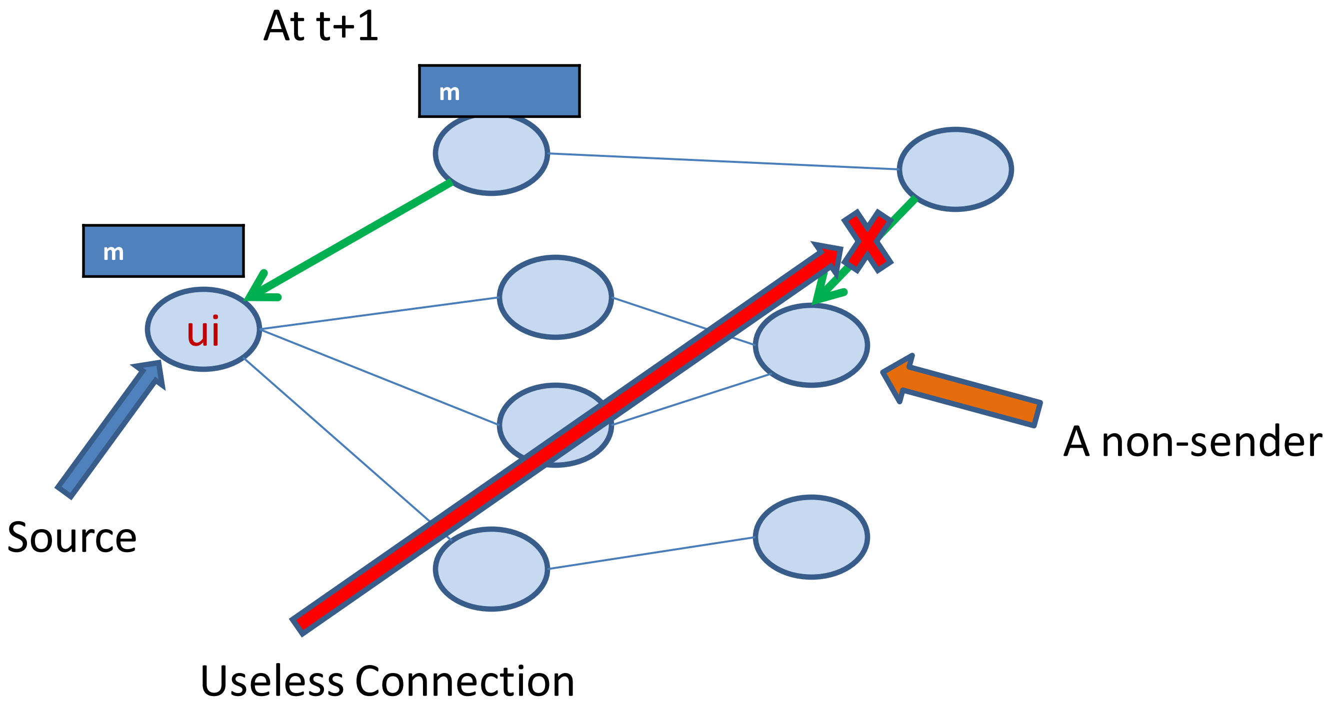

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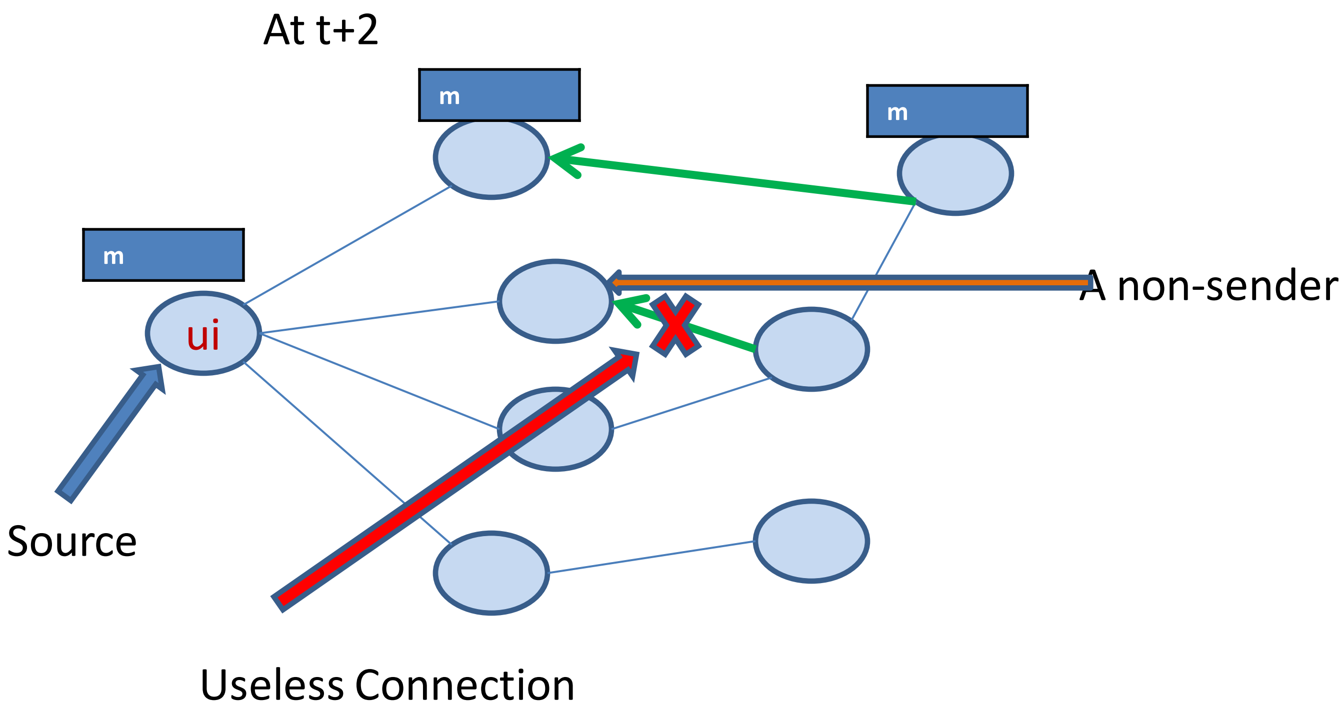

Metrics

- Broadcast Time T*
  - Time from the point the source starts sending the first packet to the point when all the agents in the network have received the entire message
    - Expected broadcast time: E(T)
  - T_i : minimum time at which the system has *i* senders

- Broadcast Wastage C^*_m
  - Measures the number of useless contacts, i.e., the contacts when no packet is transferred
  - $C^*_m = (C_l - C_p)/C_l$, where
    - C_l ➔ the total number of links
    - C_p ➔ the number of successful links

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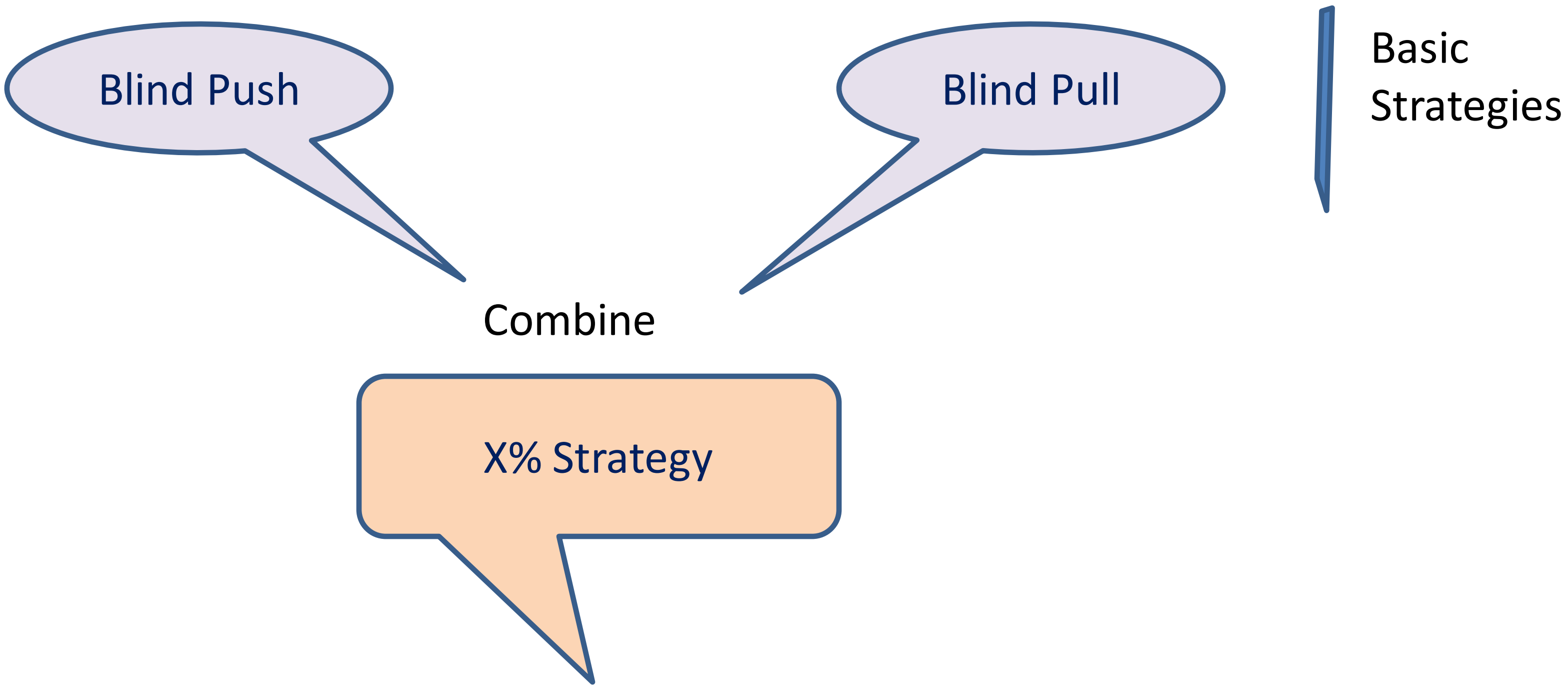
Algorithms for Message Transfer

Blind Push

Blind Pull

Basic Strategies

Algorithms for Message Transfer



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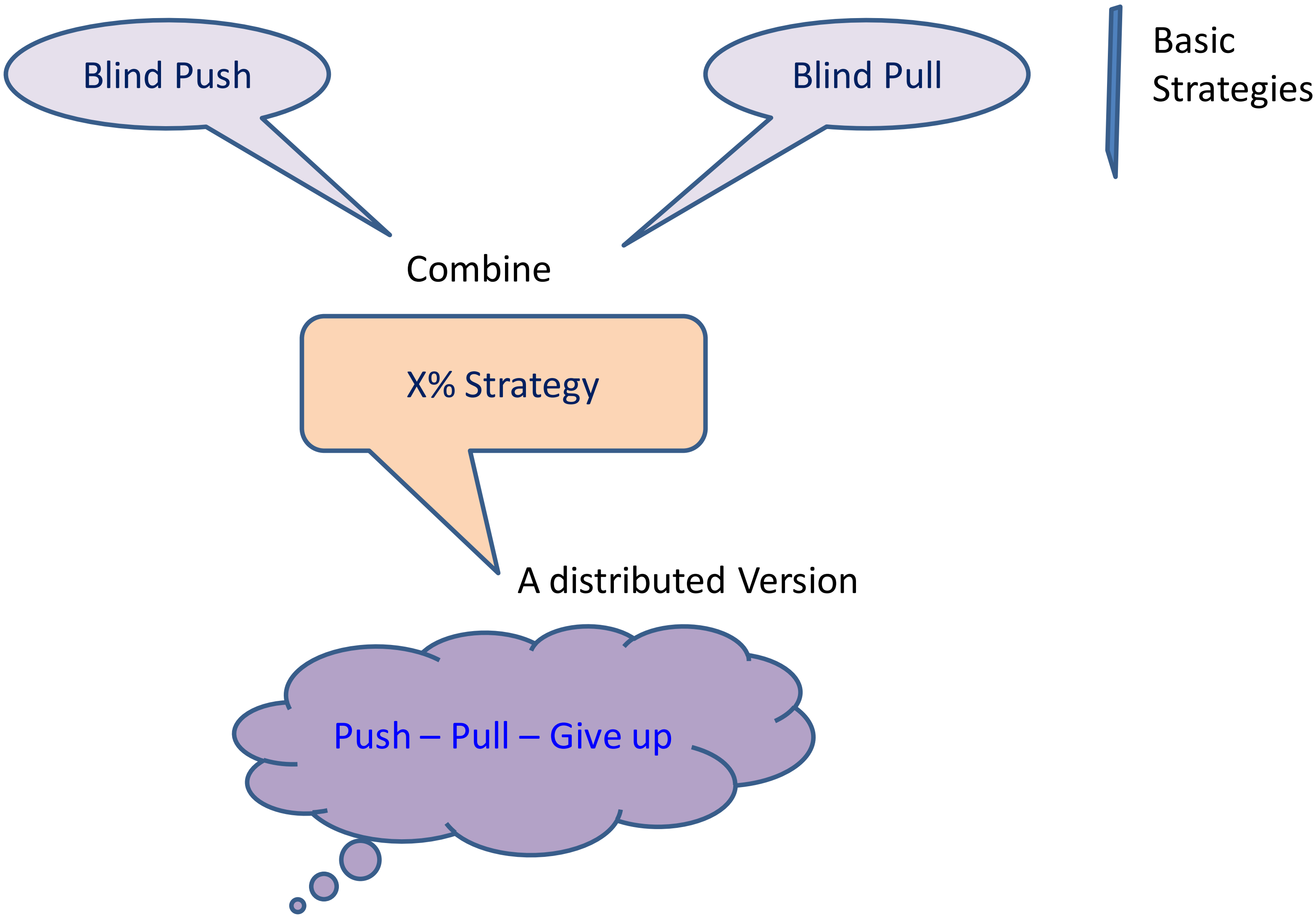
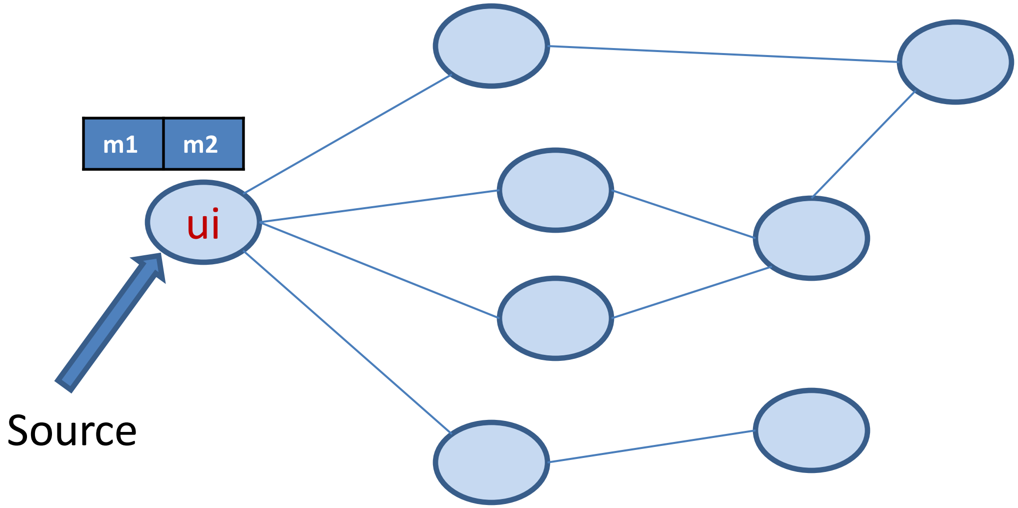


Blind Push (B-P) Technique



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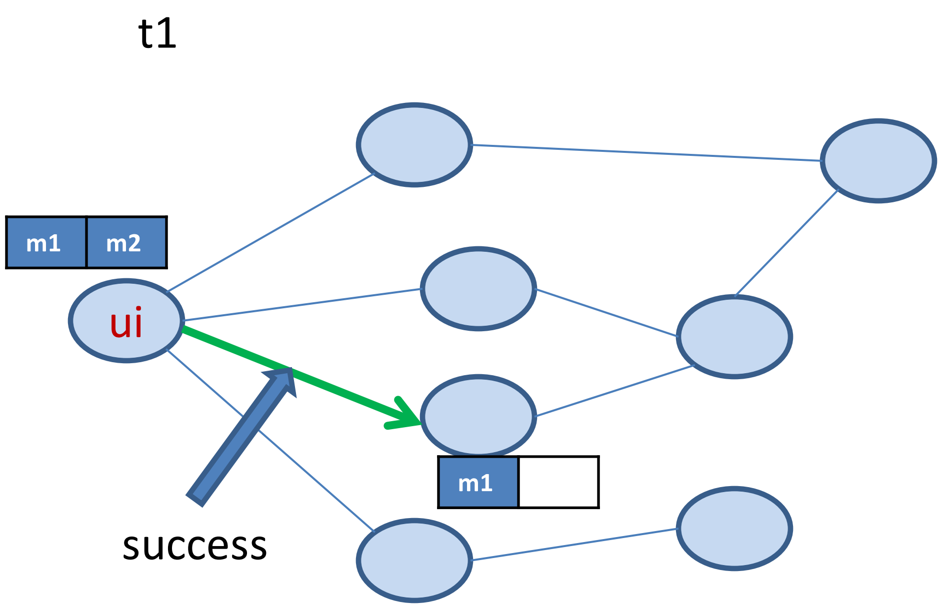

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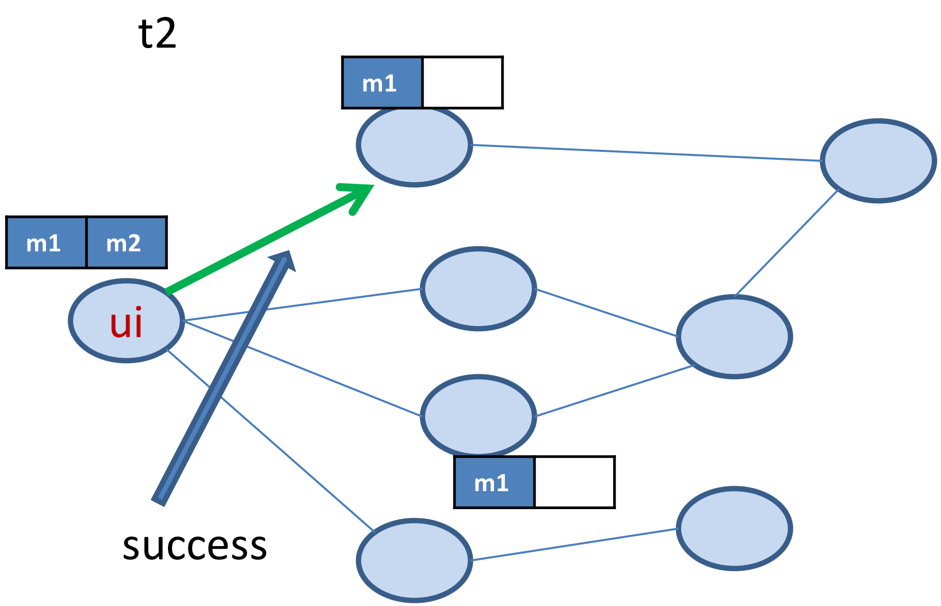

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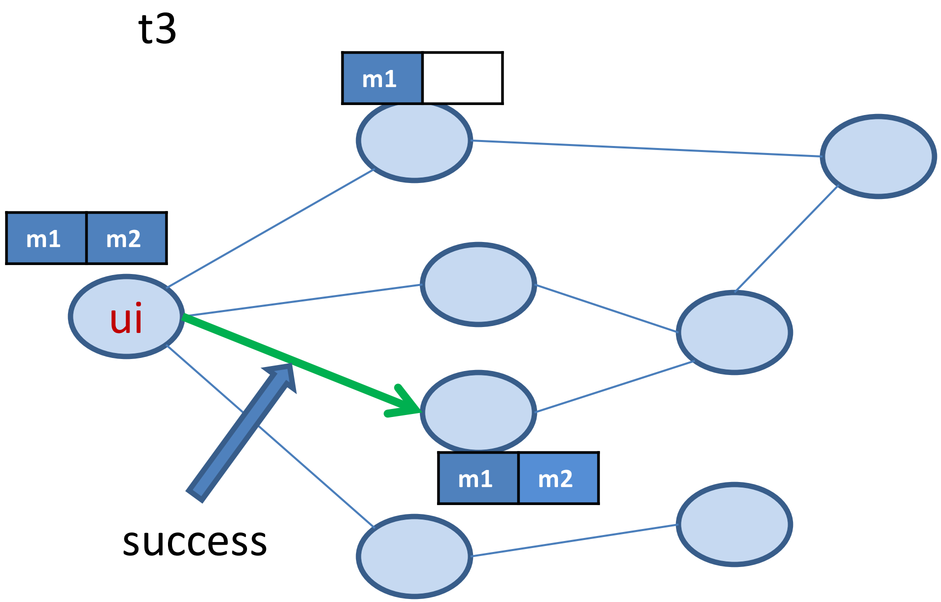

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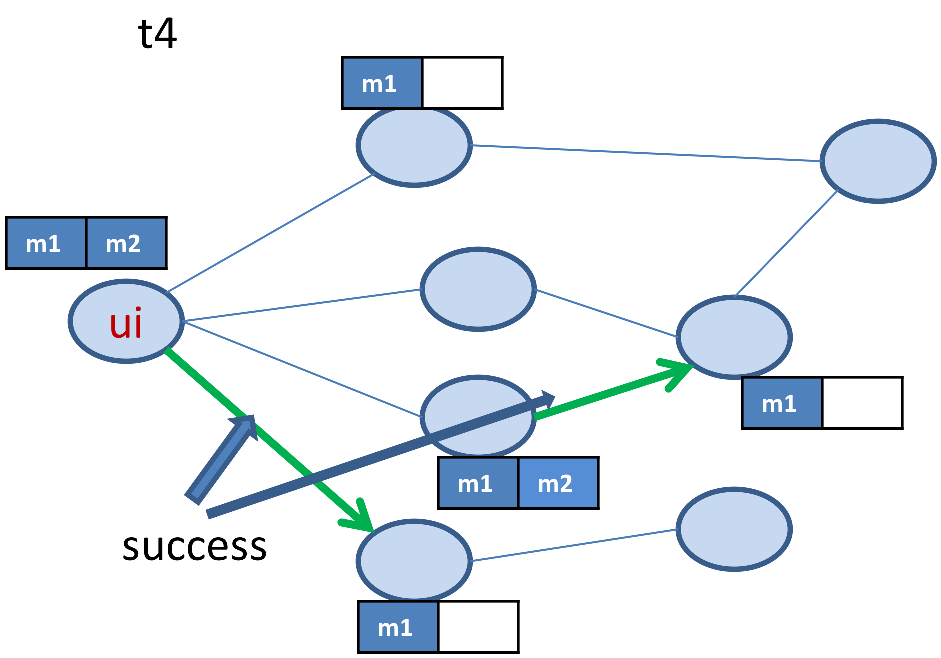

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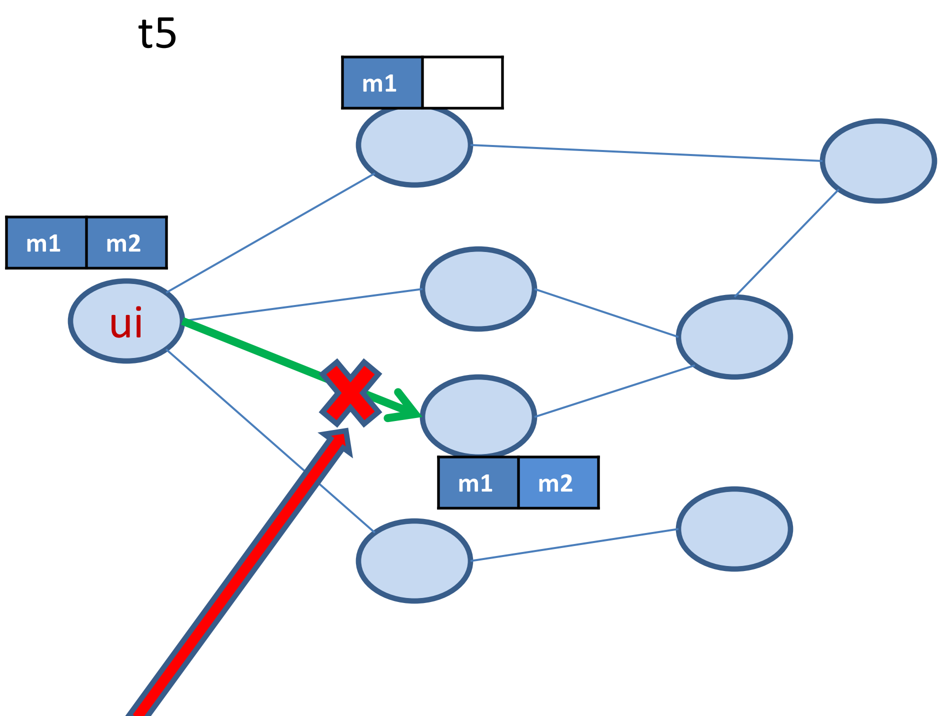

No transfer, hence useless contact

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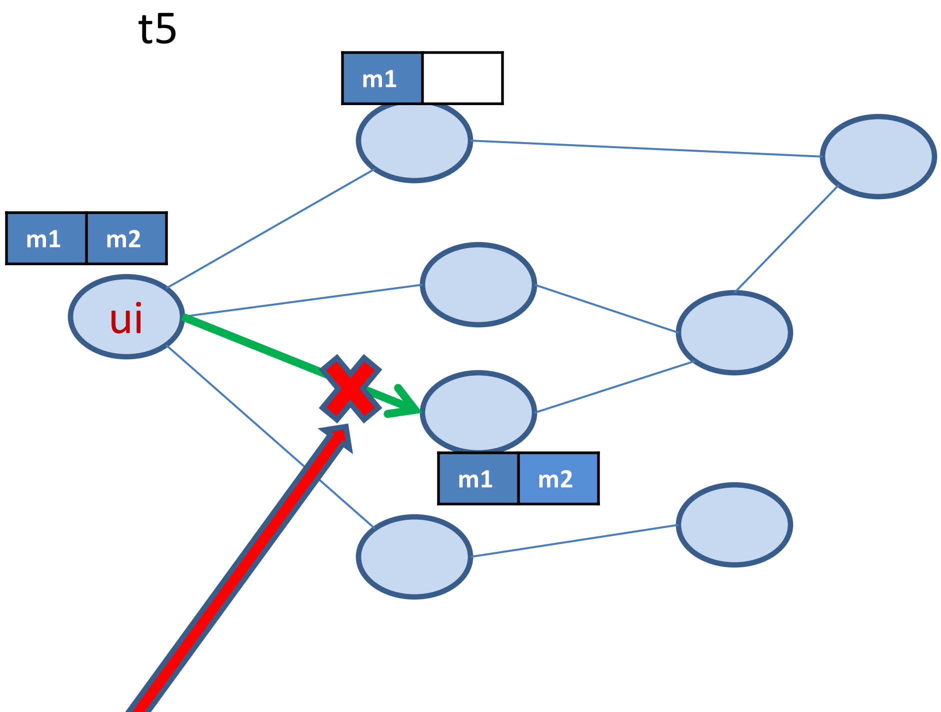


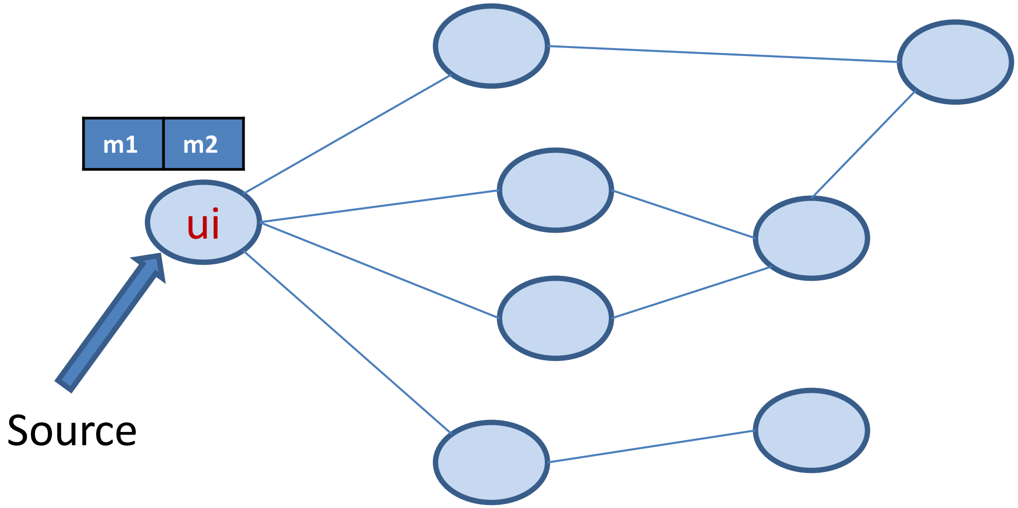
No transfer, hence useless contact

Such failures will be significant towards the end of the broadcast

Blind Push (B-P) Technique

How to reduce such failures towards the end?

Blind Pull Technique



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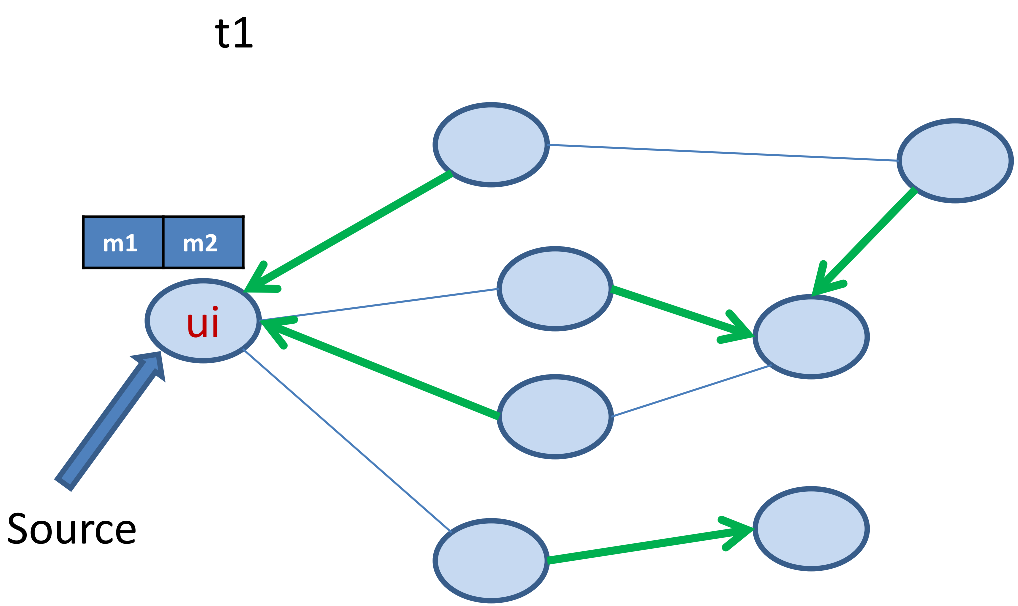

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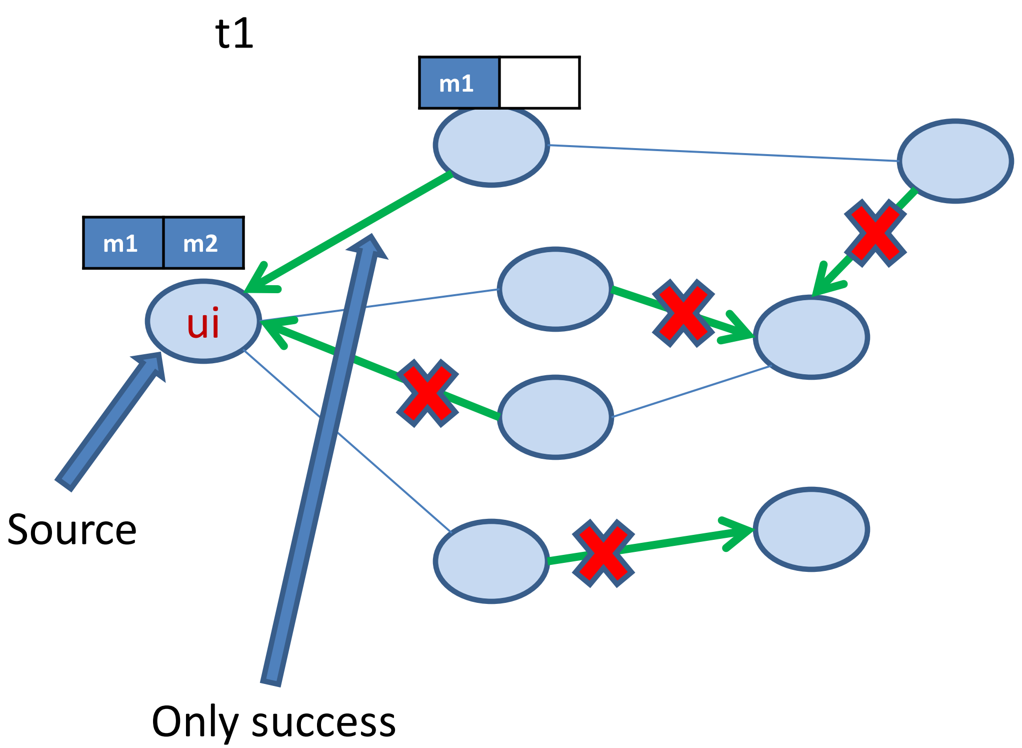

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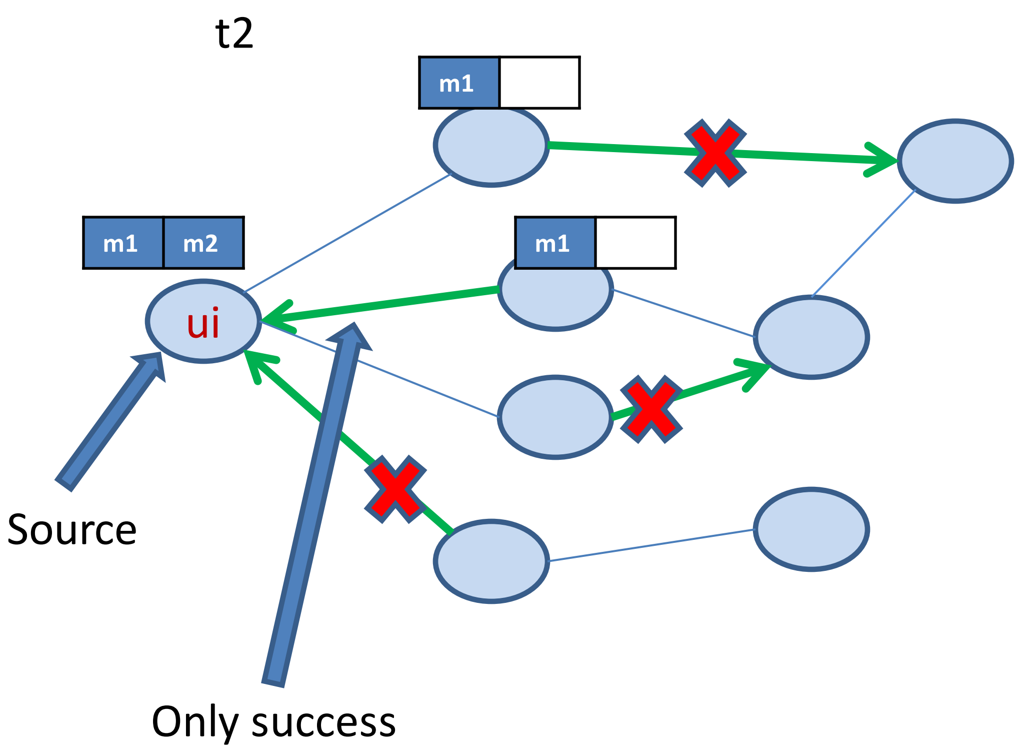

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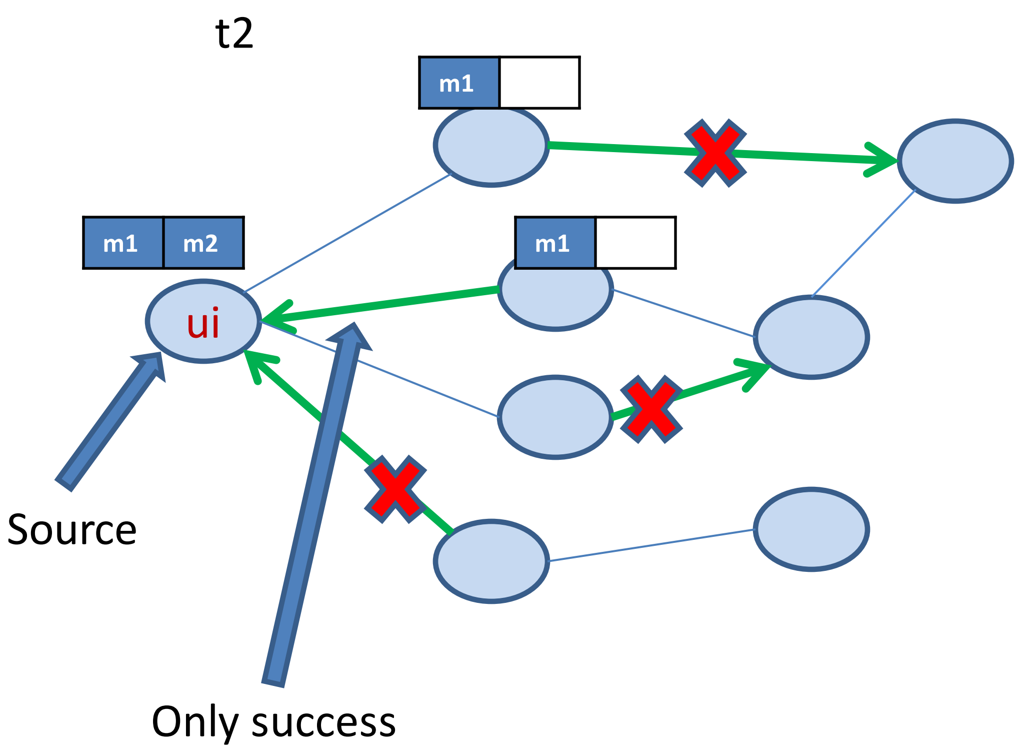
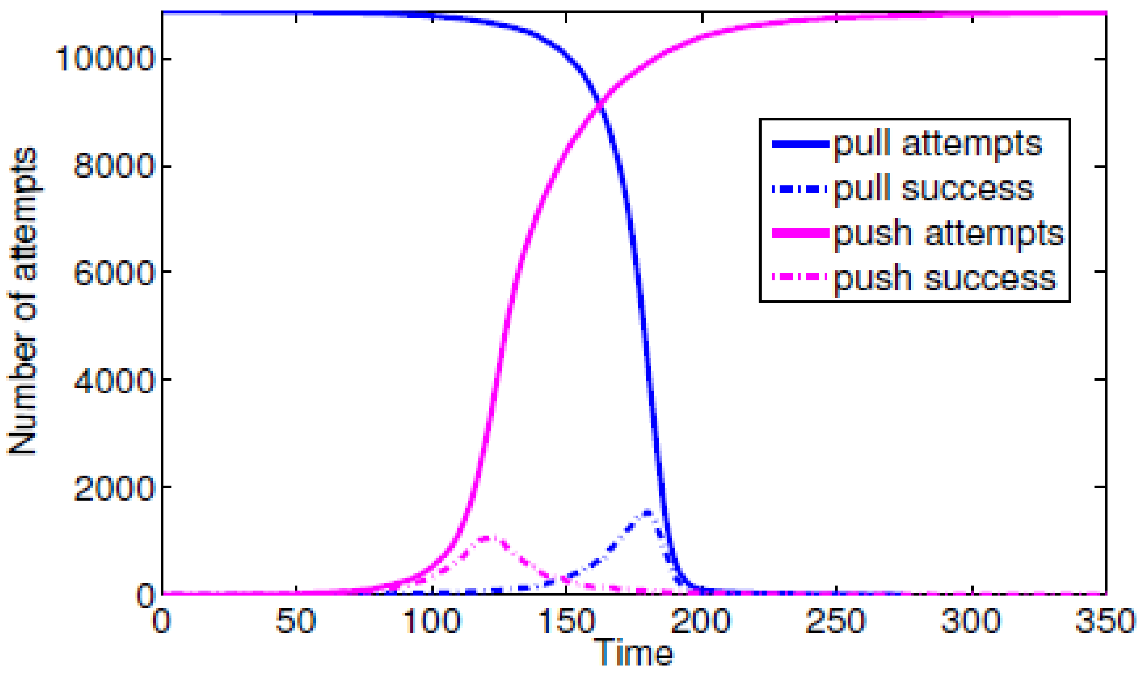


How to reduce initial failures?

Deeper analysis of the algorithms



- Blind push and blind pull are complementary to each other
- How to take advantages of them and combine?

X% Push-Push Strategy (X-P-P)

- X-P-P combines the advantages of blind push and blind pull

- The process
  - Starts with blind push (B-P)
    - to avoid potential wastage at the beginning
  - After some x% of agents becomes sender, the process converts to blind pull
    - To avoid wastage at the ending

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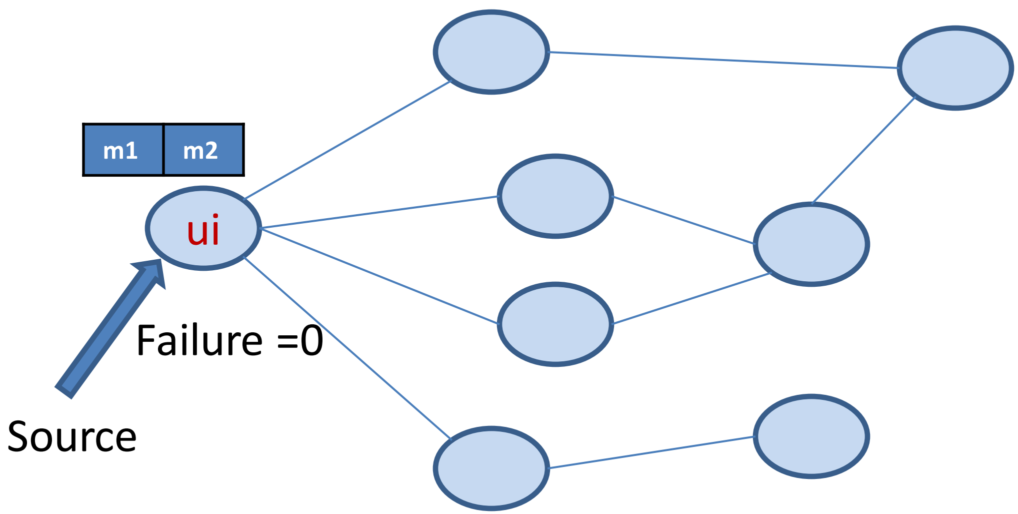
- But, how to estimate x in X-P-P because the system is a envisioned as distributed system?

Push-Pull-with-Giveup (P-P-G)

- An approximation of X-P-P to fit distributed environment
- Sender nodes stops "pushing" after a threshold number of failure "pushes"
- Receiving (i.e., non-sender) nodes starts pulling once a packet got received



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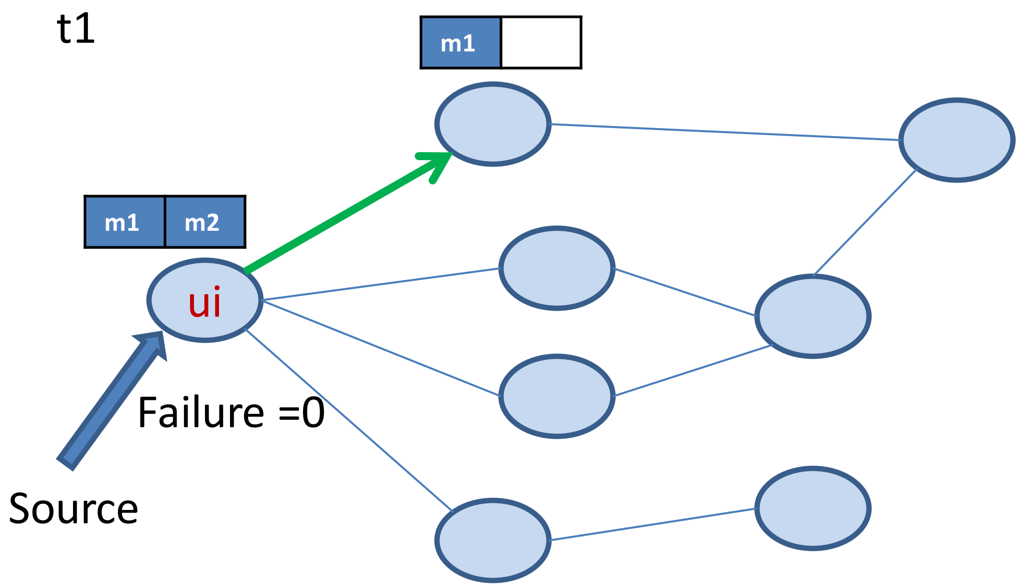

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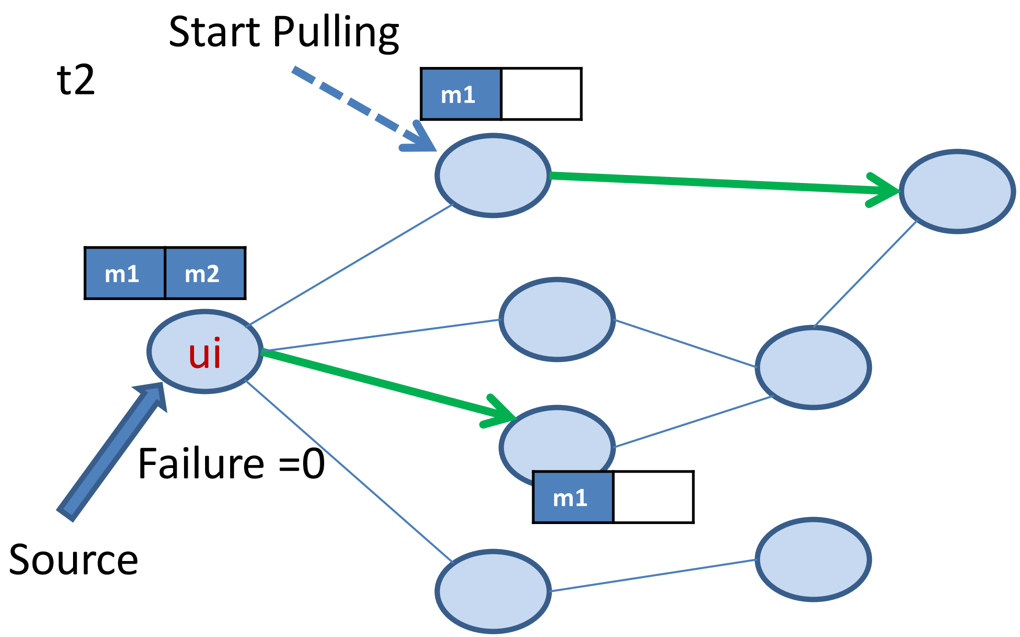

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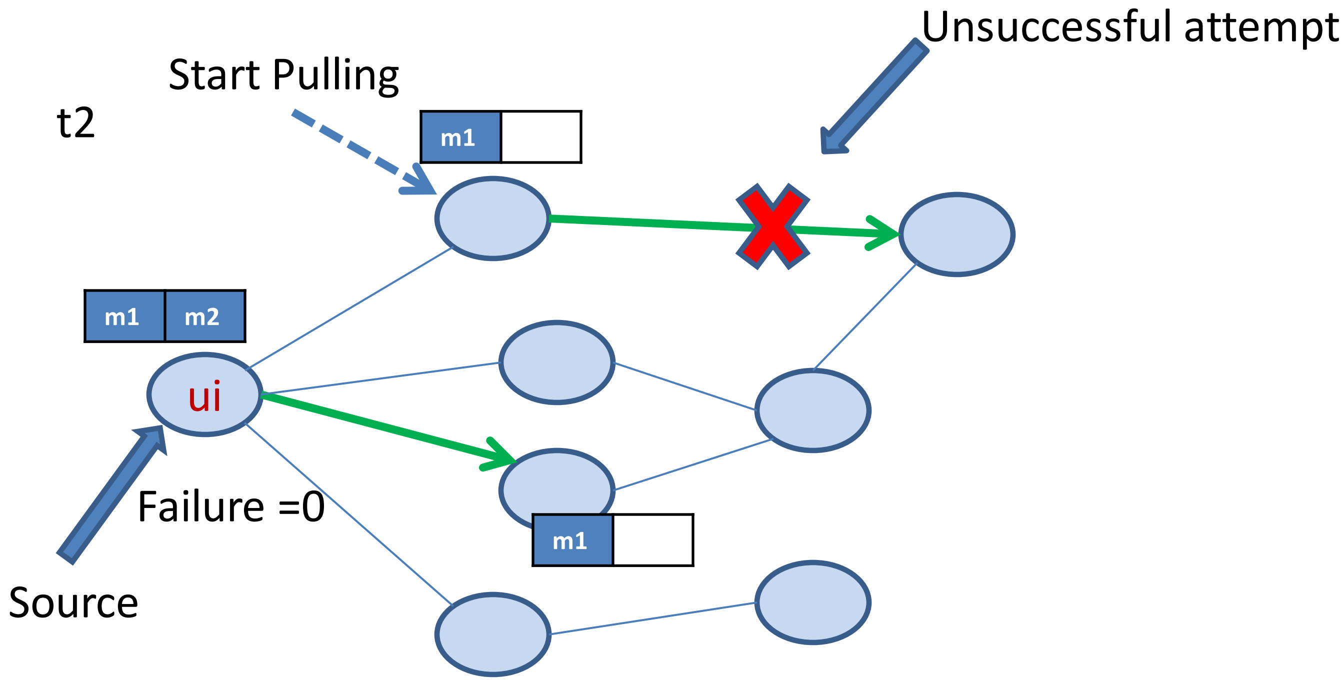

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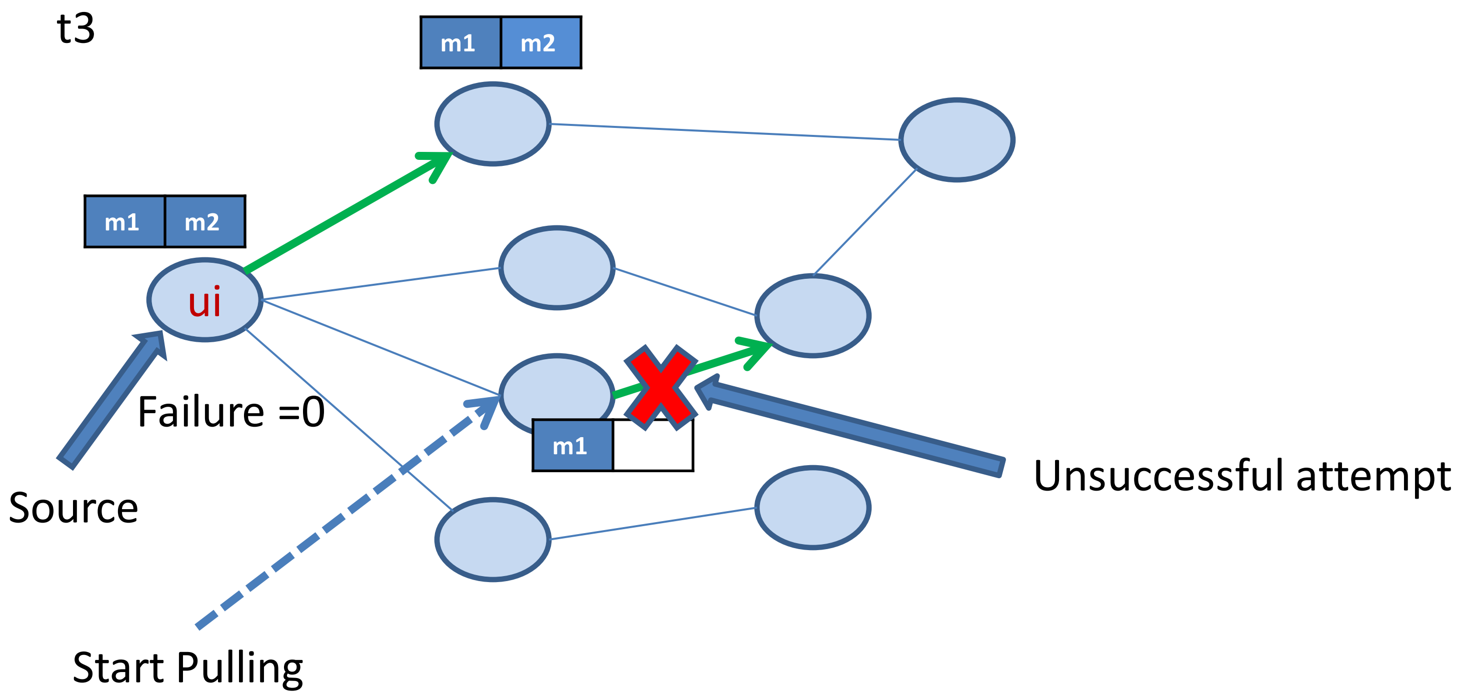

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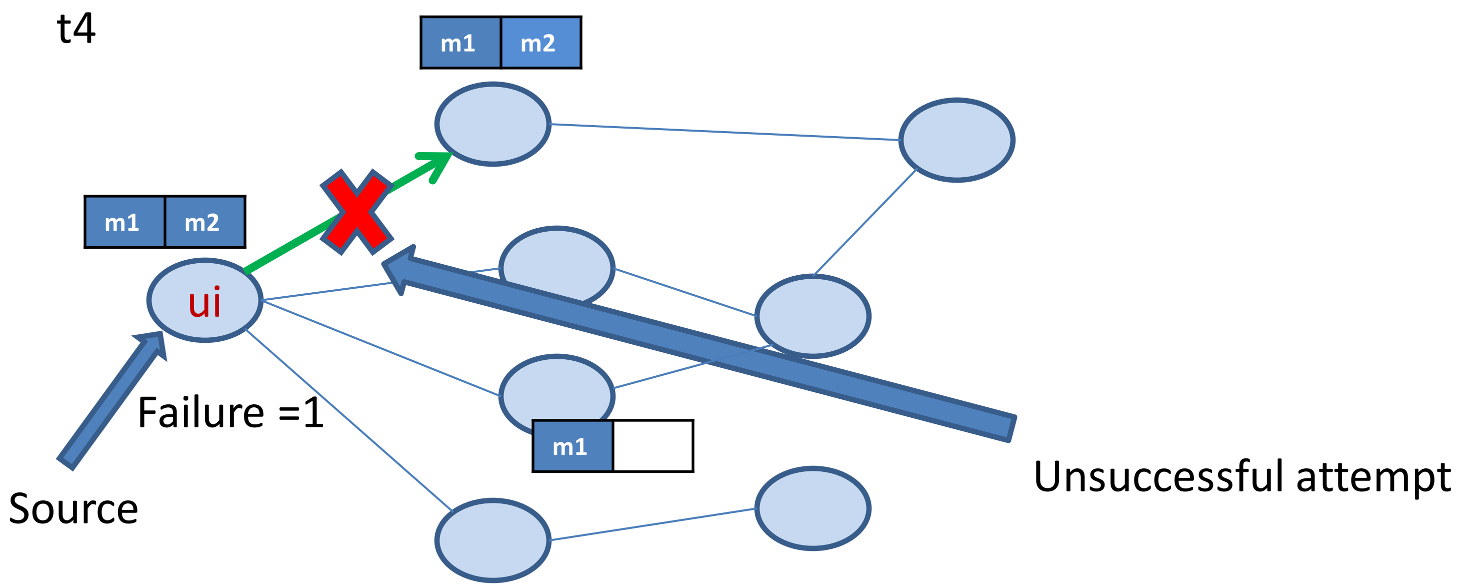

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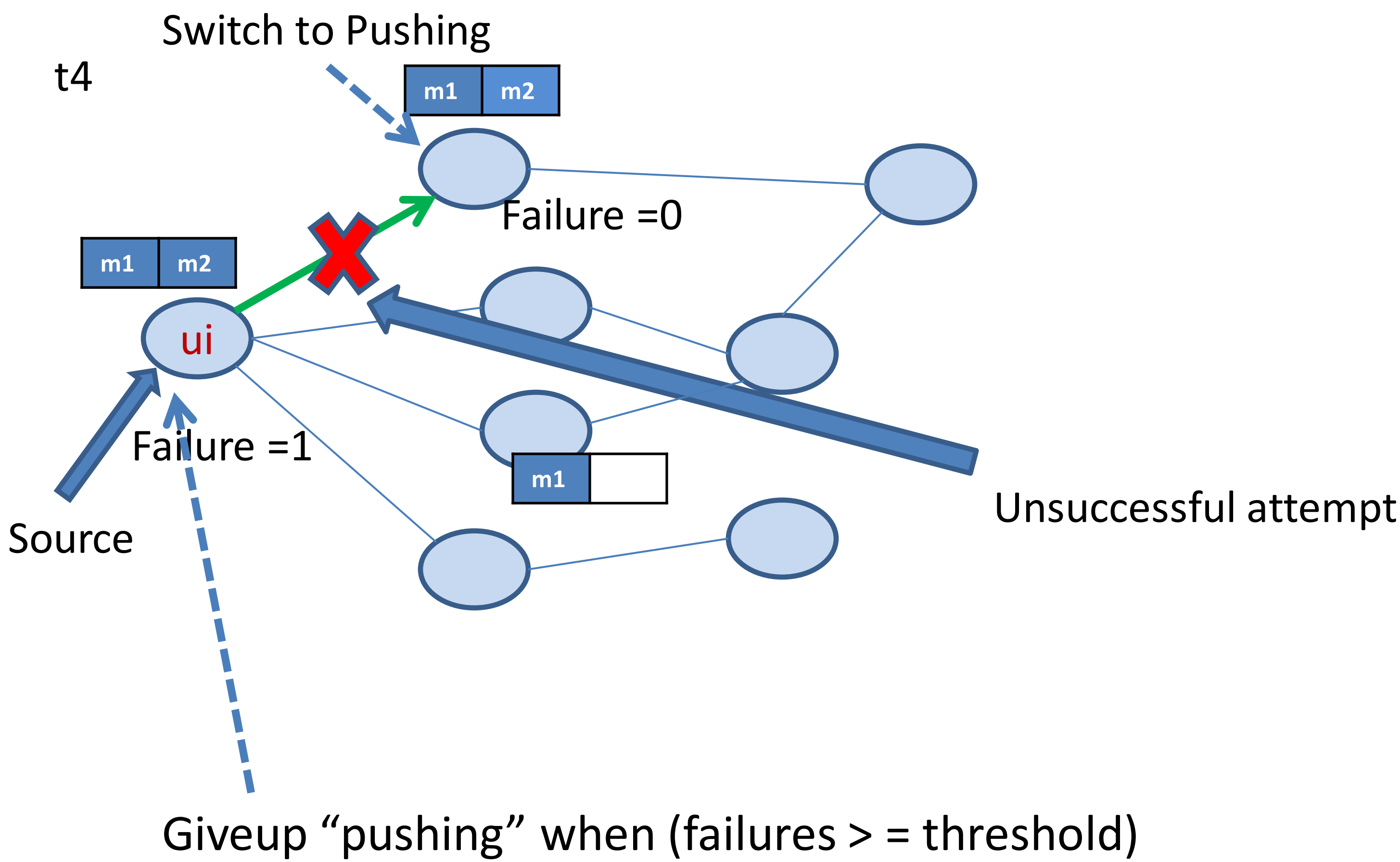

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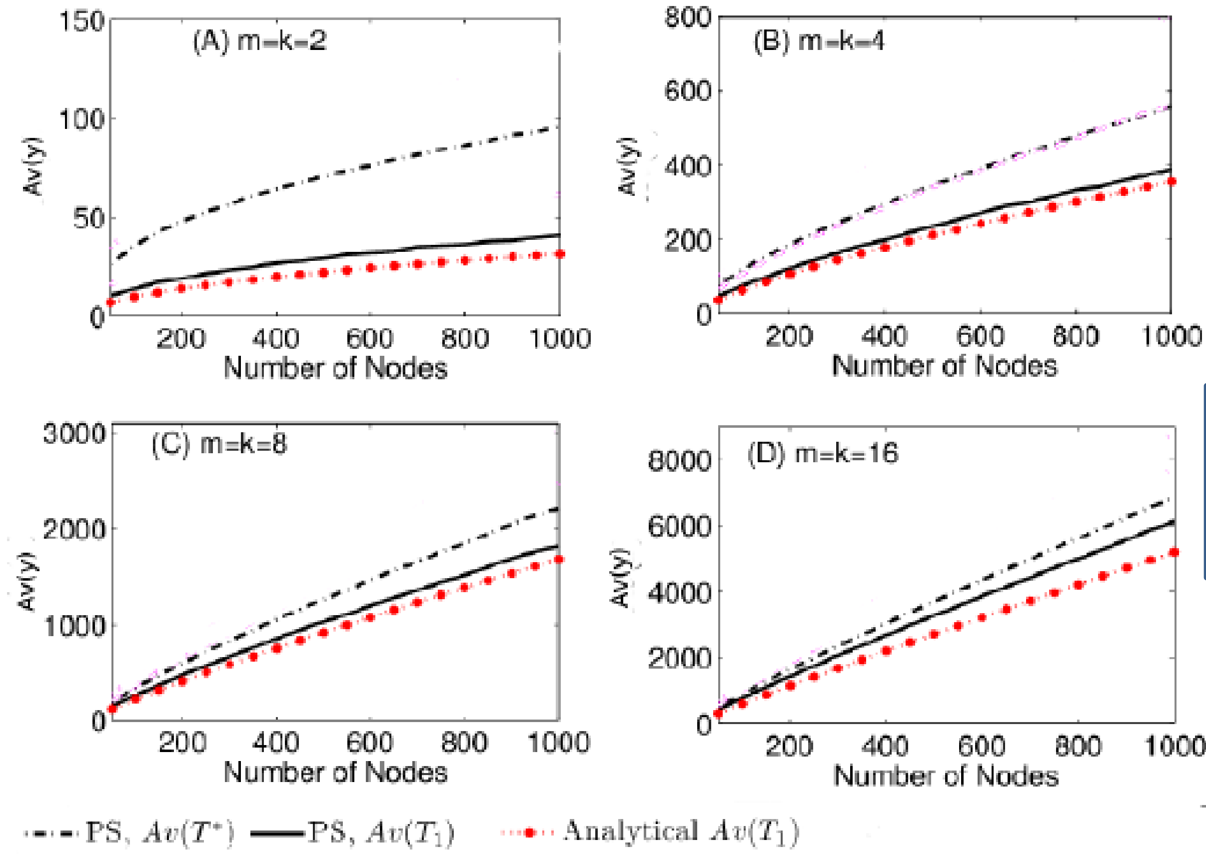
Deeper analysis of the algorithms

- Blind Push (B-P) is simple and analytically tractable
  - lets try to see analytical results
- Analyze B-P on a synthetic graph topology of dynamic graphs, like
  - Complete graph, regular graph, regular tree
- Then, find some simulation results on real network topologies, like
  - Gnutella network

Blind Push (B-P) on Complete Graph

- For a complete graph topology we report
  - Expected broadcast time E(T)
  - Expected time $E(T_1)$ to get first sender other than source



Note: $E(T_1)$ is an indicator of E(T)

Estimation of T_1

- Ratio of T* and T_1 converges to a constant
- Estimation of T_1

Estimate T_1 as:

$$\Pr\{T_1 = t\} = \frac{t-1}{n}\prod_{l=1}^{t-2}\left(1 - \frac{l}{n}\right), t \geq 2$$

- Sketch: consider a message has 2 packets (for simplicity)
    - Minimum time required to create first sender = 2
    - Pr(T_1 = t) implies that up to t- 1 time only those nodes are selected that has no packet, and at t, a node out of t-1 nodes are selected

Estimation of T_1

- Thus,

$$\Pr\{T_1 = t\} = \underbrace{(1 - \frac{1}{n})(1 - \frac{2}{n})(1 - \frac{3}{n})...(1 - \frac{t-2}{n})}(\frac{t-1}{n})$$

This part ensures that none of t-1 nodes got selected up to time t-1

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- Generalized for k-packets message

$$\Pr(T_1 = t) \sim \frac{t^{k-1}}{(k-1)!n^{k-1}} \prod_{i}^{t} \left(1 - \frac{i^{k-1}}{(k-1)!n^{k-1}}\right)$$

$$\sim \frac{t^{k-1}}{(k-1)!n^{k-1}} e^{-\frac{t^k}{k!n^{k-1}}}$$

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$$E(T_1) = \sum t * \frac{t^{k-1}}{(k-1)!n^{k-1}} e^{-\frac{t^k}{k!n^{k-1}}} \Rightarrow n^{\frac{k-1}{k}}$$

Blind Push on Sparse Networks

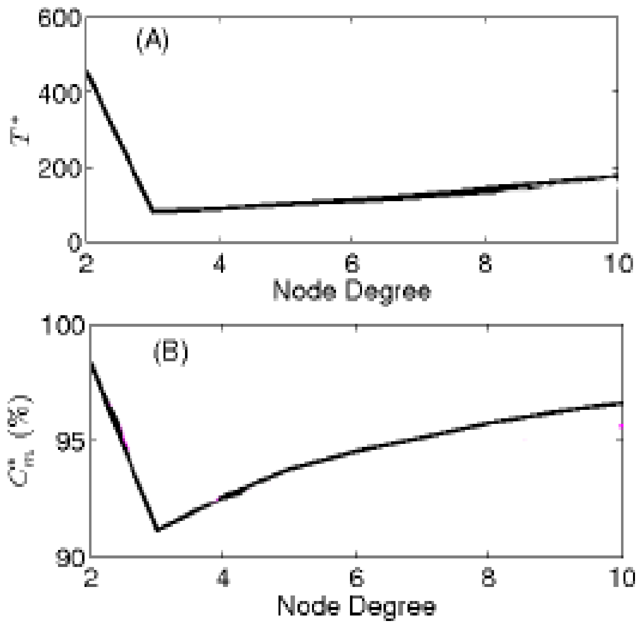


Figure : Regular tree

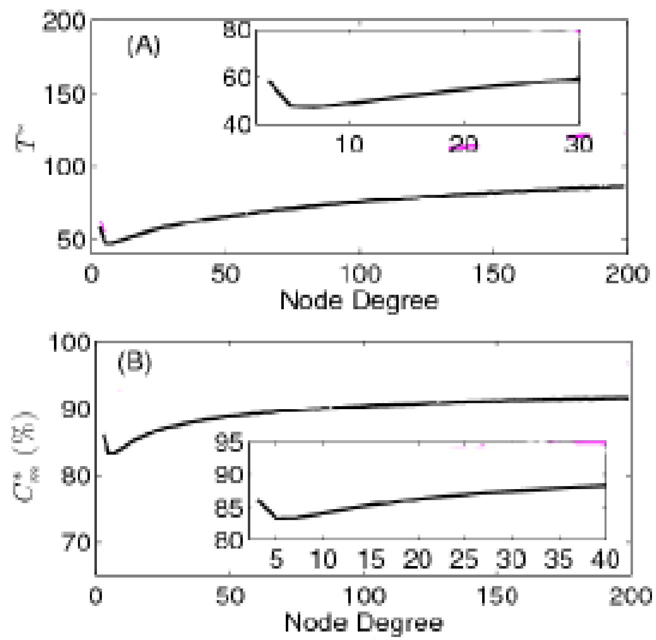


Figure : Regular graph

- An optimal degree d can be found where broadcast delay and wastage can be minimum

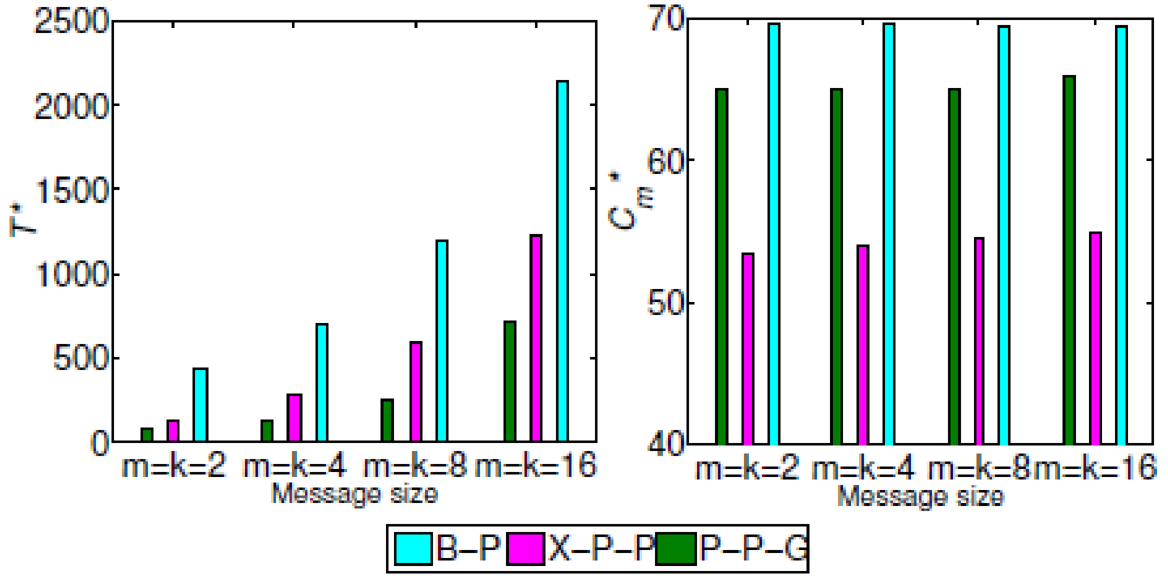
B-P, X-P-P, & P-P-G on Real Network Topology

- Three snapshots of Gnutella network (taken in 2002)

Data set	#Nodes	#Edges	Avg. degree
Gnutella_1	10876	39994	7.34
Gnutella_2	8717	31525	7.24
Gnutella_3	22663	54693	5.82

Comparison of the Broadcast Algorithms

- The optimal X (point where the system switches to Pull) for the three networks are 50, 50 and 60 respectively



	Gain of P-P-G in Delay		Gain of P-P-G in Wastage	
	Over B-P	Over X-P-P	Over B-P	Over X-P-P
Gnutella_1	5.45	1.5	1.10	0.75
Gnutella_2	5.9	1.6	1.06	0.72

Observations

- With respect to B-P, we gain in both broadcast time and wastage while with respect to X-P-P we gain only in broadcast time

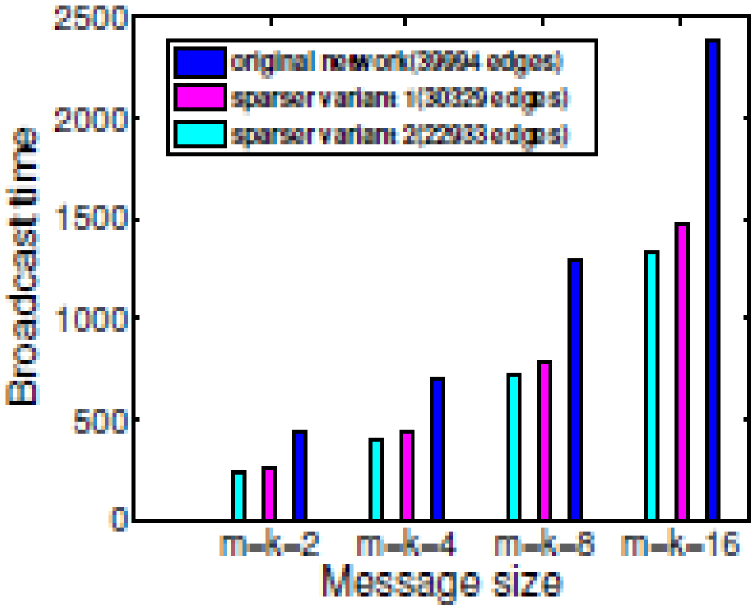
- X-P-P provides optimal trade-o between time and wastage but is not practically implementable

- P-P-G gives best trade-o and can be implemented in distributed fashion with negligible computational overhead

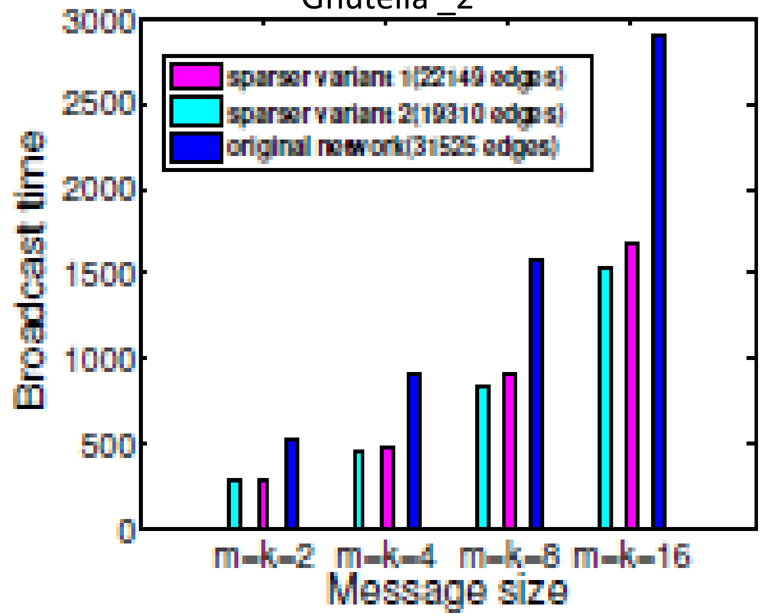
Effect of Sparsity on Broadcast Delay on Real Data Set

- Already observed presence of an optimal degree in case of synthetic networks
- To perform simulations on the sparser variants of the Gnutella networks
  - removed a set of the network edges keeping the network connected

Gnutella _1



Gnutella _2



The broadcast time reduces significantly for the sparser variants

1) Problem definition
2) Setup
3) Algorithms of Message Transfer
4) Deeper analysis of the algorithms
5) Conclusions

Conclusion

- Define a new problem in the space of information dissemination and broadcast in dynamic networks
- The speed of broadcast for segmented message differs from single message case
- Presence of an optimal d (average degree) irrespective of topology where the broadcast is most efficient
- Sparseness leads to faster broadcast

Thank You