# Delay Tolerant Networks

DTN

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Note: Some of the slides are directly copied from sources.

# How DTNs differs from Traditional networks?

In telecommunications, the round-trip delay time (RTD) or round-trip time (RTT) is the length of time it takes for a signal to be sent plus the length of time it takes for an acknowledgment of that signal to be received. Thistime delay therefore consists of the propagation timesbetween the two points of a signal.

- Internet environment
  - End-to-end RTT is not large.
  - Assume that there exists an end-to-end path between communicating nodes.
  - E2E reliability is present.

- DTN characteristics
  - Very large delays (Tolerate delay and disruption).
  - Intermittent and scheduled links.
  - Different network architectures.
  - Conventional protocols fail.

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# Delay Tolerant Network Routing

- Traditional networks
  - Route from source to destination exists when the message leaves the source
- Delay tolerant networks
  - No pre-existing route
  - Message is forwarded as nodes encounter each other
  - Message traverses the route over time as the nodes move around

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# The Bundle Layer

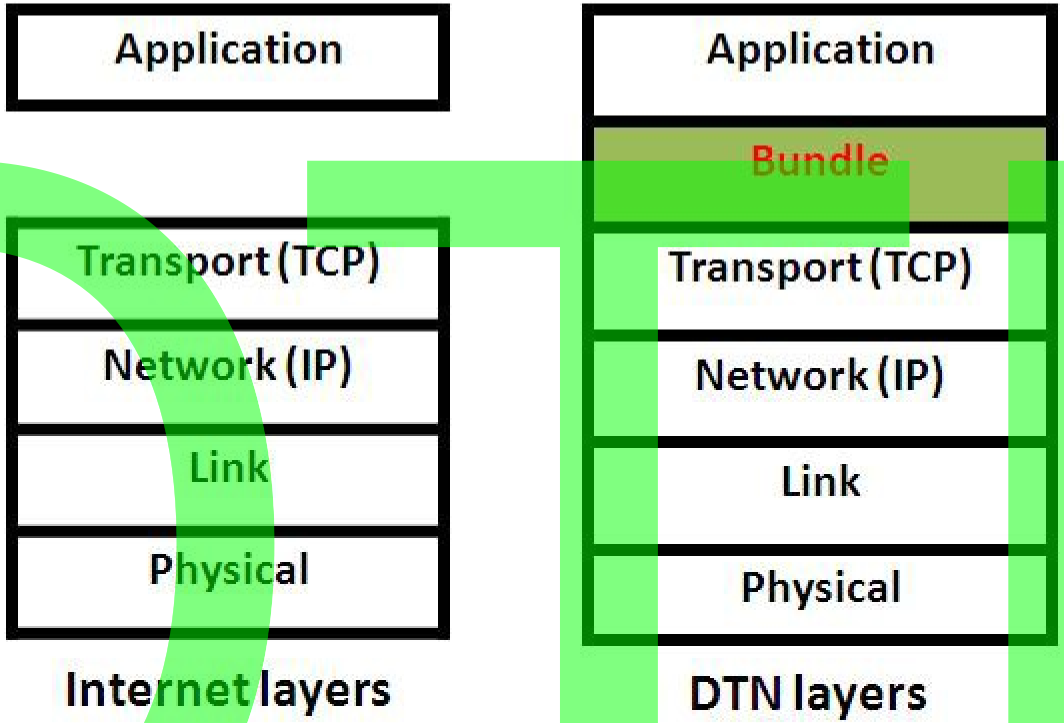


Figure: The protocol layers [1]

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# Evolution of DTNs

- The idea of DTN comes from Inter PlaNetary (IPN) internet project [2].
- Fall generalized the concept presented in [2] into a delay-tolerant networking architecture.
- Opportunistic Mobile Networks (OMNs) and Pocket Switched Networks (PSNs) are specialized subdomains of DTNs.
    - In OMNs communication links do not always exist. Rather, mobility of the nodes provides them with opportunities to communicate with the other nodes in the network.
    - A PSN is formed by the portable devices such as, smart phones and PDAs, carried by human beings. PSNs communicate among themselves by global connectivity's or devices communicate opportunistically.

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# Sub-classes of DTNs

- Two prominent sub-classes:
  - Opportunistic Mobile Networks (OMNs)
  - Pocket Switched Networks (PSNs)

- OMNs [Huang2008]:
  - Intermittent communication opportunities
- PSNs:
  - Portable devices carried by human beings
  - Use global connectivity's, if available
  - Otherwise, communicate opportunistically

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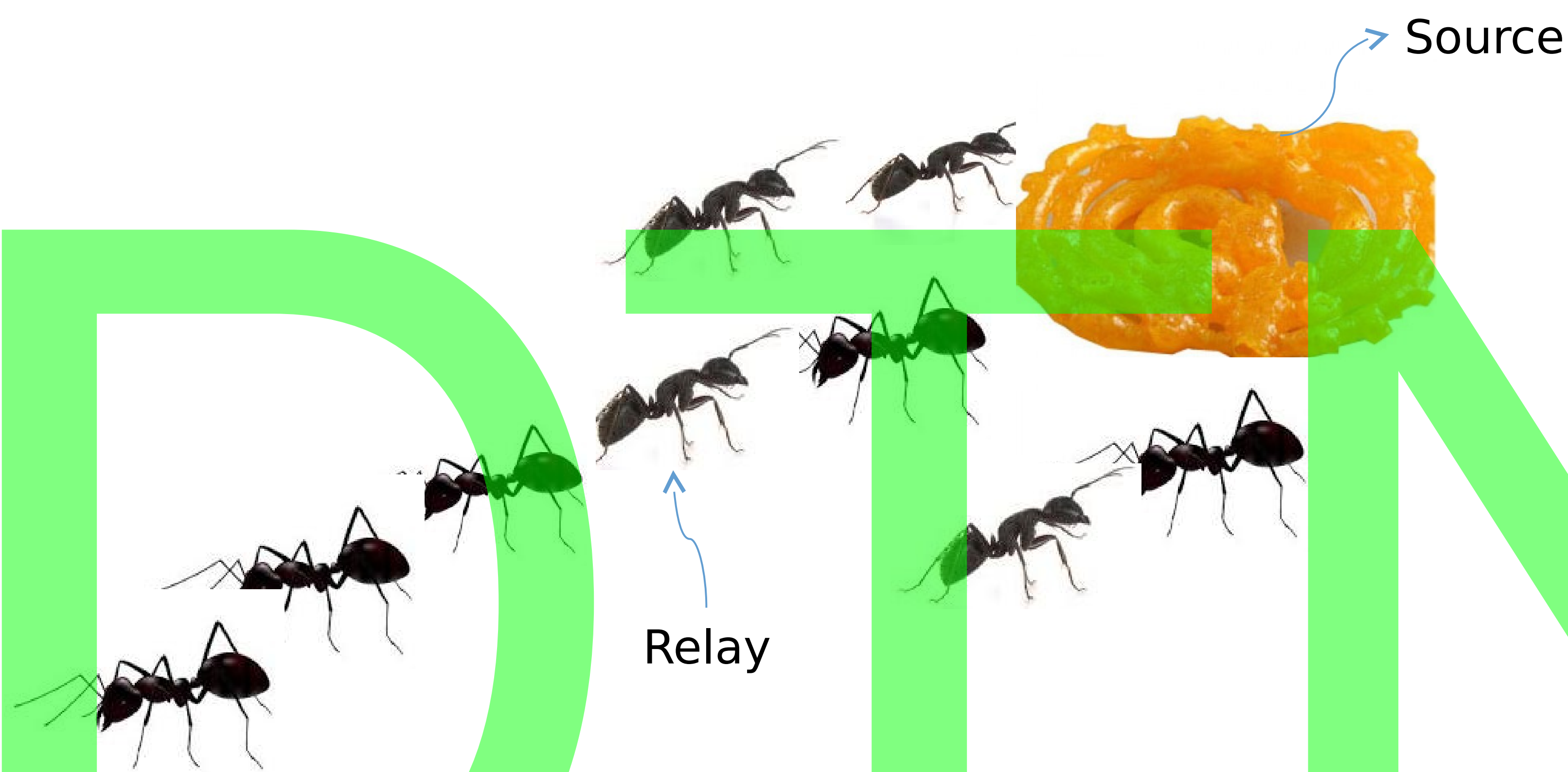
# How does it work?

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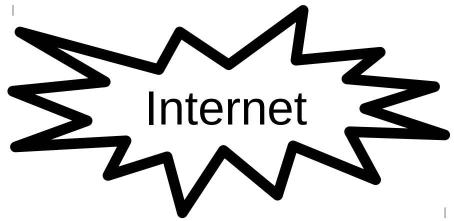

OR


Transfer

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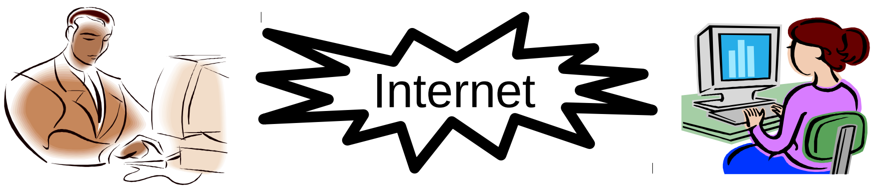
- Fact 1: Wireless is everywhere !

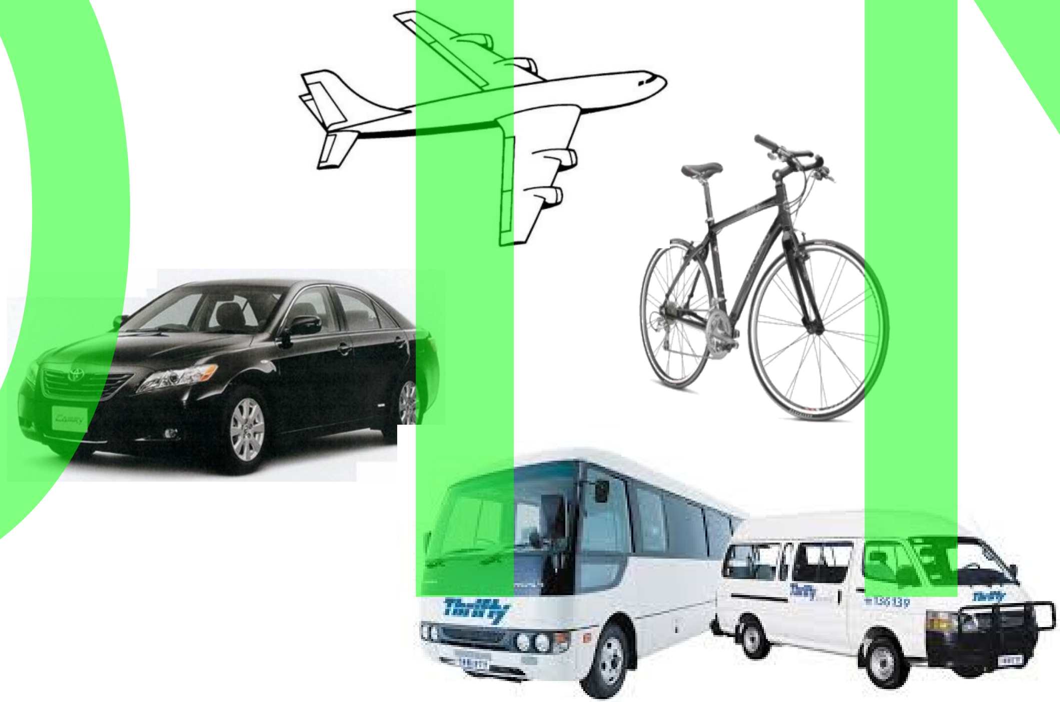


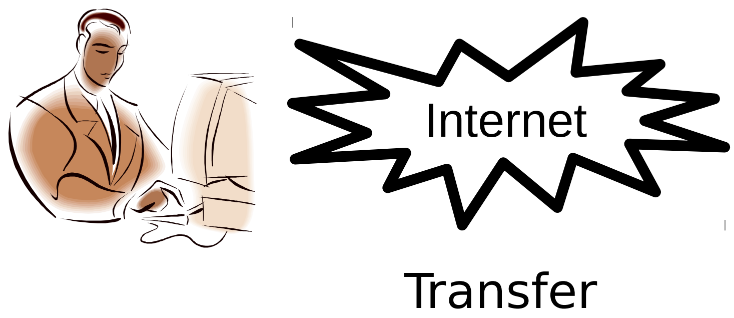

Transfer

**OR**

# DTN

- Fact 1: Wireless is everywhere !
- Fact 2: We need mobility!






**OR**

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- Fact 1: Wireless is everywhere !
- Fact 2: We need mobility!
- Fact 3: Storage is cheap and vast!


# **Message Transfer in** Traditional Networks

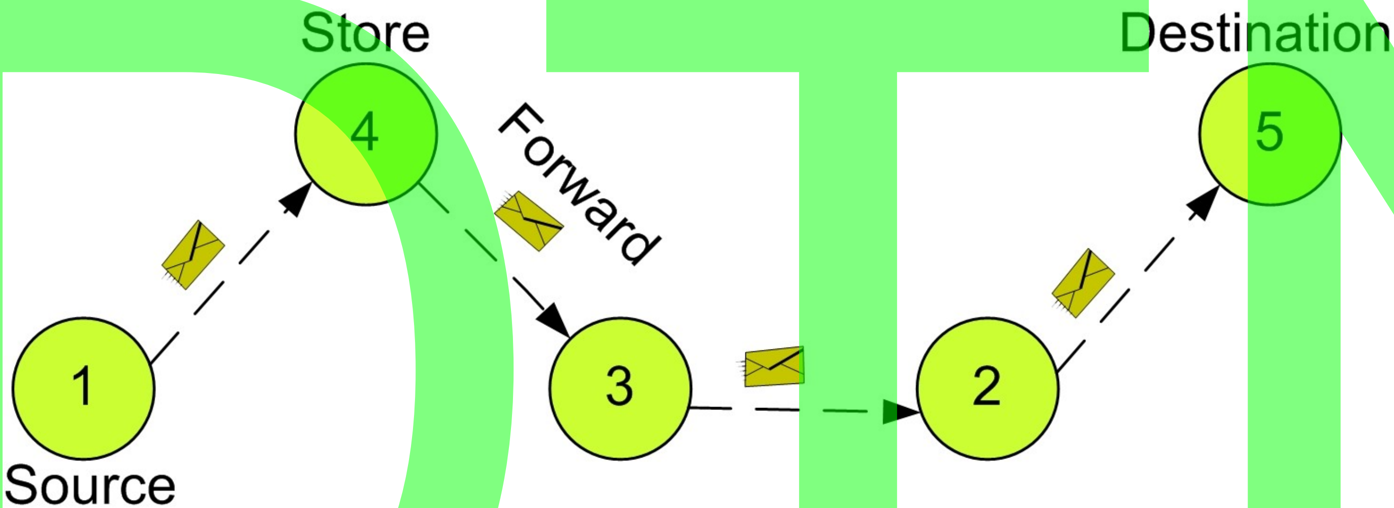


Figure : Store-and-forward paradigm.

# Message Transfer in OMNs

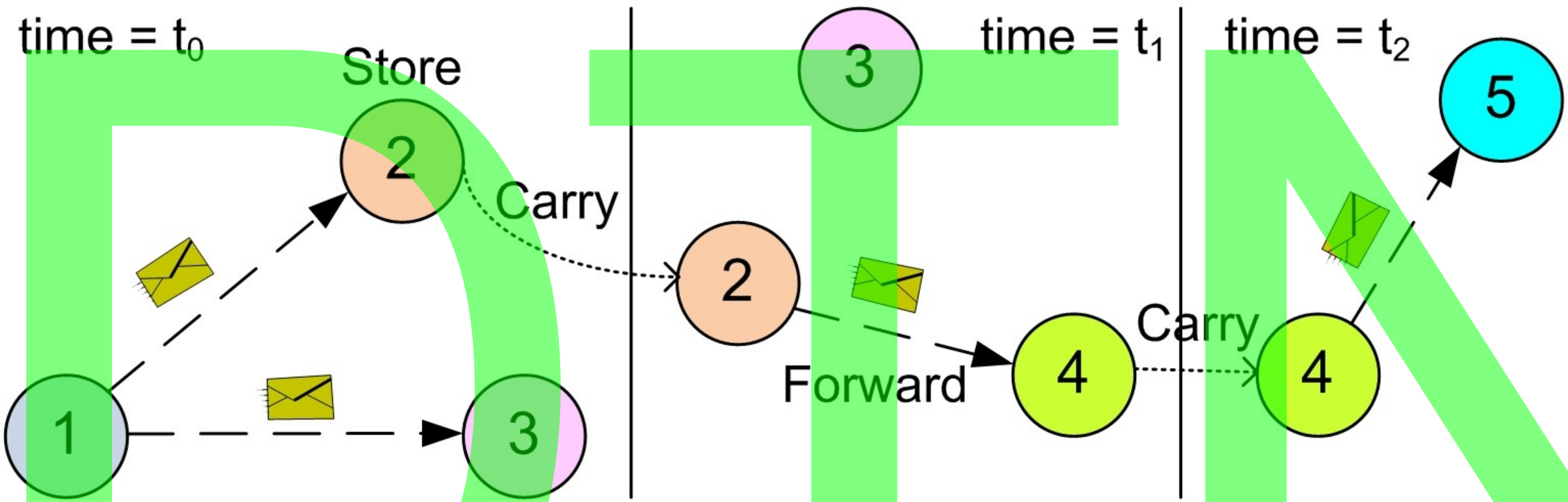


Figure : Store-carry-and-forward paradigm.

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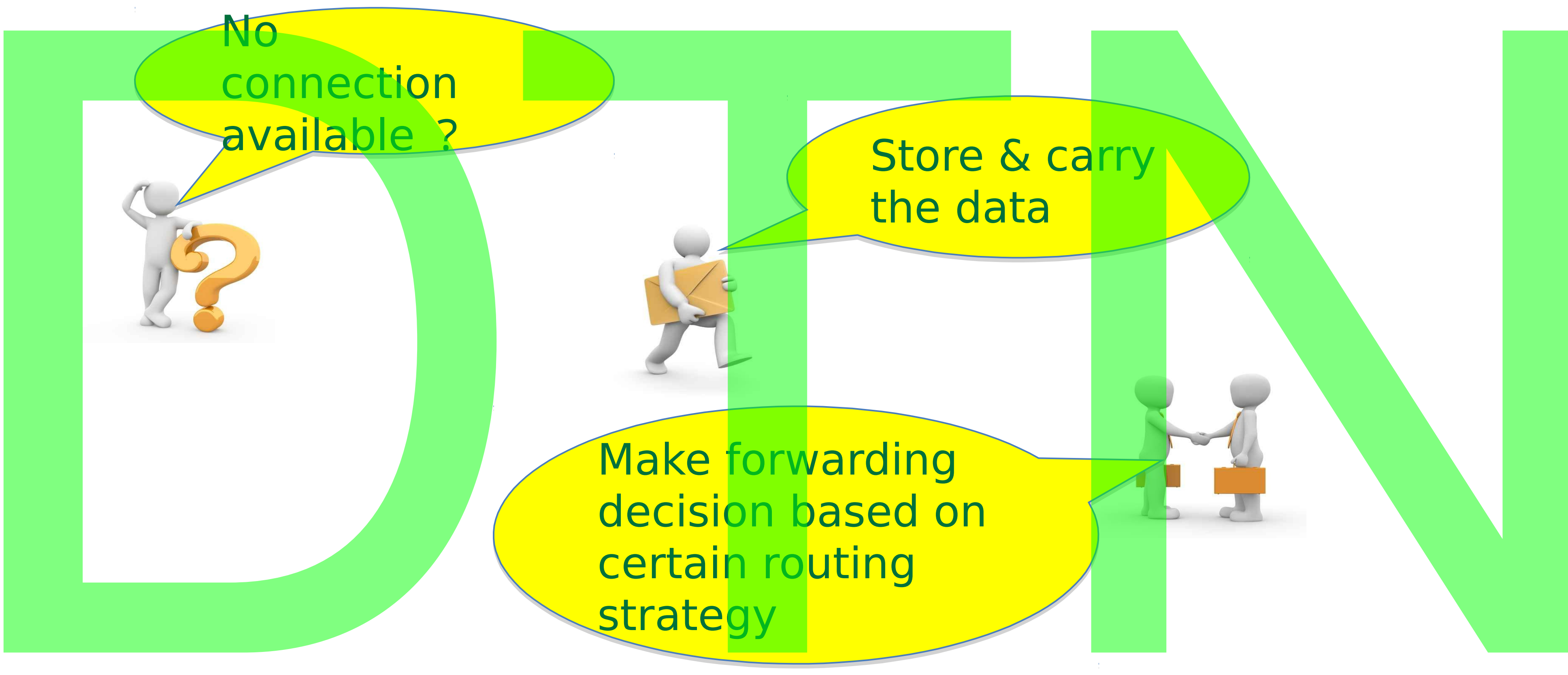
# Message Transfer in OMNs



# Forwarding vs. Replication

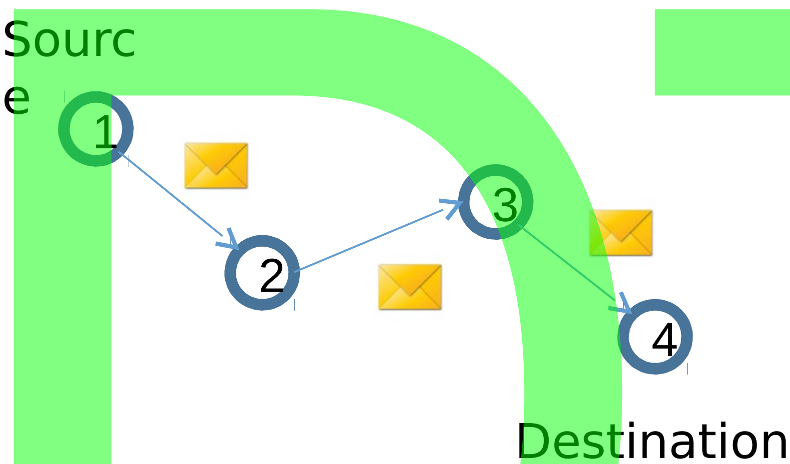



Figure: Message forwarding

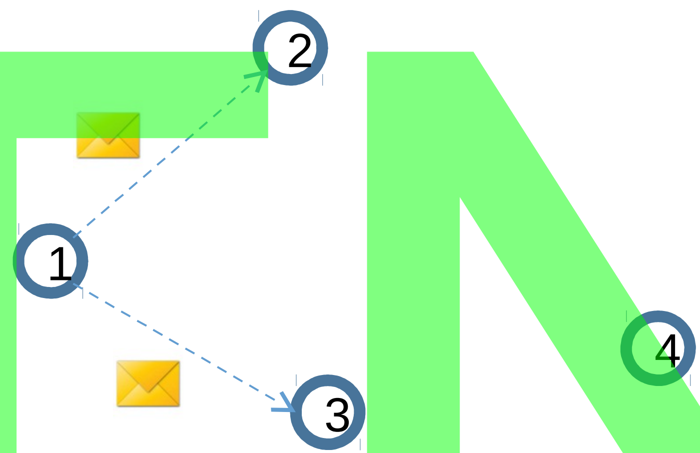



Figure: Message replication

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# Challenging Issues

- Routing : Challenge is to ensures high delivery ratio of the messages
- Cooperation : Critical issue due to intermittent connectivity's among the nodes

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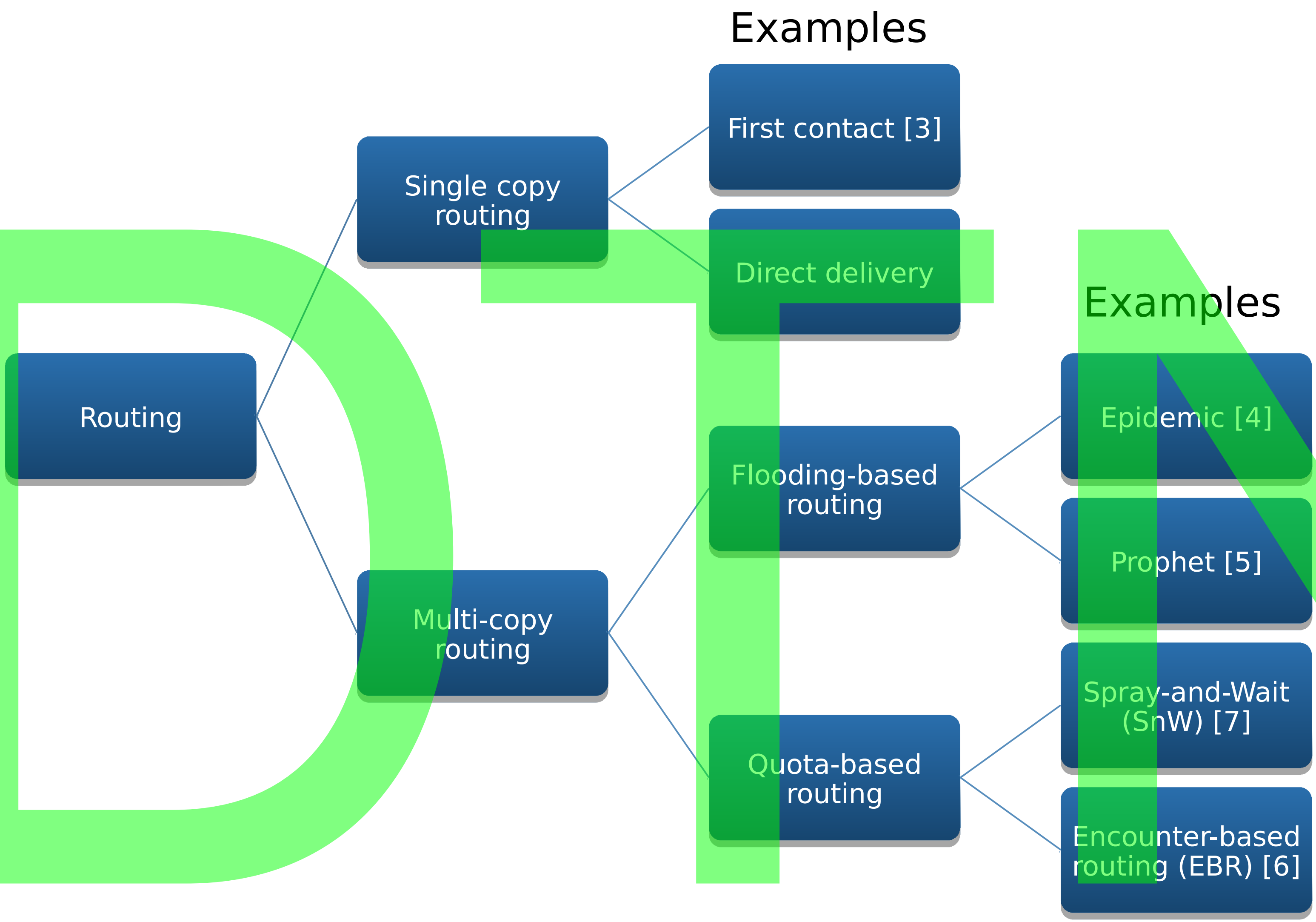
# Routing in DTNs

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# Routing in DTNs (Cont.)

- **Single copy routing:** A single copy of the message is transferred to the contacted node.
  E.g., First contact [2] and Direct delivery routing protocols.

- **Multi-copy routing:** Multiple replicas of a given message are created.
  - **Flooding-based routing:** Unlimited copies of the message are forwarded to the different nodes.
    E.g., Epidemic [6] and Prophet [3] routing protocols.
  - **Quota-based routing:** A fixed number of replicas are transmitted to the different nodes.
    E.g., Spray-and-Wait (SnW) [5] and Encounter-based routing (EBR) [4] routing protocols.

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# First Contact Routing

- First contact routing protocol was proposed by Jain et al. “Routing in a Delay Tolerant Network”, In Proc. ACM Sigcomm, pages 145–158, 2004 [3].

- Contact: A contact is an opportunity to send data over an edge. More precisely, it is a specfic edge and a corresponding time interval during which the edge capacity is strictly positive.

- Messages: A message is a tuple (u; v; t; m), where u is the source of the message, v is the destination, t is the time at which the message is injected into the system and m is its size (messages can be of arbitrary size). The set of all messages is called the traffic demand.

- Message is forwarded to the first available contact.
- If more than one contacts are available, message is forwarded to a randomly chosen edge.

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# Epidemic Routing

- A. Vahdat and D. Becker, Epidemic routing for partially-connected ad hoc networks, Technical Report CS-2000-06, Duke University, 2000.
- Forward message to every node encountered
- Message spreads like that of a disease in a population
- Deliver messages with high probability even when there is never a fully connected path.
- The overall goal of Epidemic Routing is to
  - maximize message delivery rate
  - minimize message delivery latency

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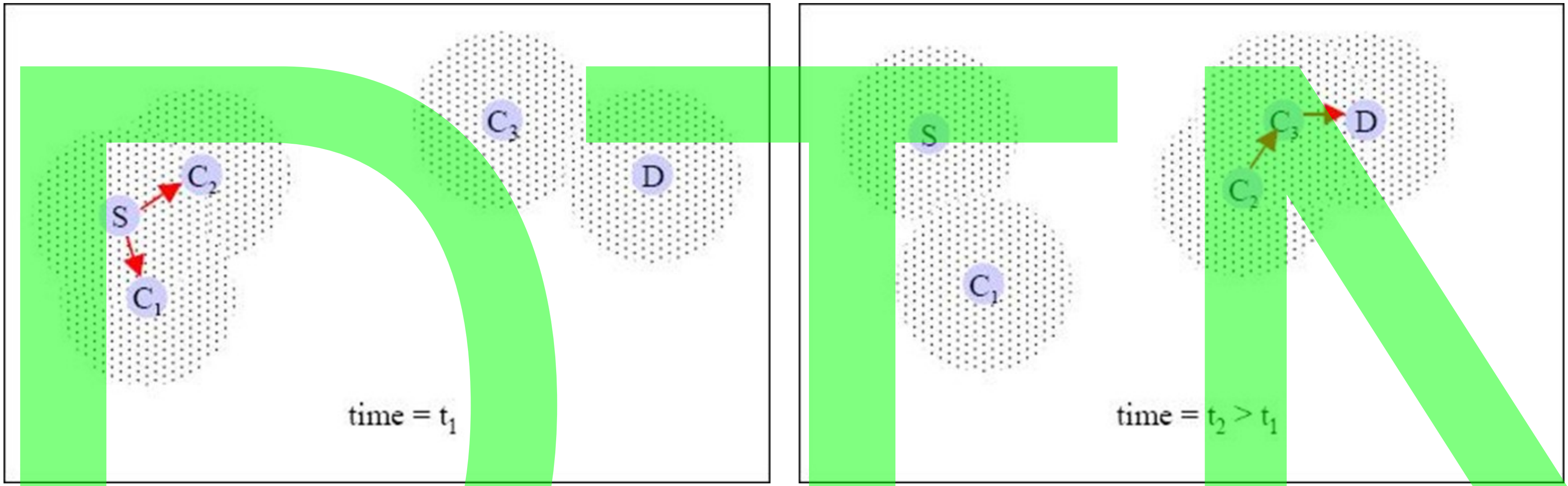
# Epidemic Routing (Cont.)

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# Prioritized Epidemic Routing(PREP)

- Prioritizes the messages for transmission and deletion using a priority function.
- Priority function is based on
  - Current cost to destination
  - Current cost from source
  - Expiry time
  - Generation time
- Inter-node costs are computed with a metric called average availability.

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# Features of PREP

PREP has two modules:

- Topology awareness
  - Helps in calculating routing costs from a node to a destination.
- Message drop and Transmit property
  - A priority scheme for deleting and transmitting message packets.

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# Topology Awareness

- Each node runs a neighbor discovery algorithm to find out its neighbors.
- Each link between two nodes has a metric called the Average Availability(AA).
- The average availability is calculated based on a short history of node link availability information.
- If a link is not available for a configured time, then it is forgotten.
- Periodically or whenever sufficient new link information is available Link State Advertisements (LSA) are exchanged between nodes.

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# Prophet Routing

- A. Lindgren, A. Doria, and O. Schelen, Probabilistic routing in intermittently connected networks, SIGMOBILE Mobile Computing Communication Review, 7(3):19–20, 2003.

- Probabilistic Routing Protocol using History of Encounters and Transitivity for Intermittently Connected Network
- Improve delivery rate of messages by keeping buffer usage and communication overhead at a low level.
- Assumes that nodes move in a predictable behavior.
- Transfers data when Delivery Predictability Value is higher at other node.

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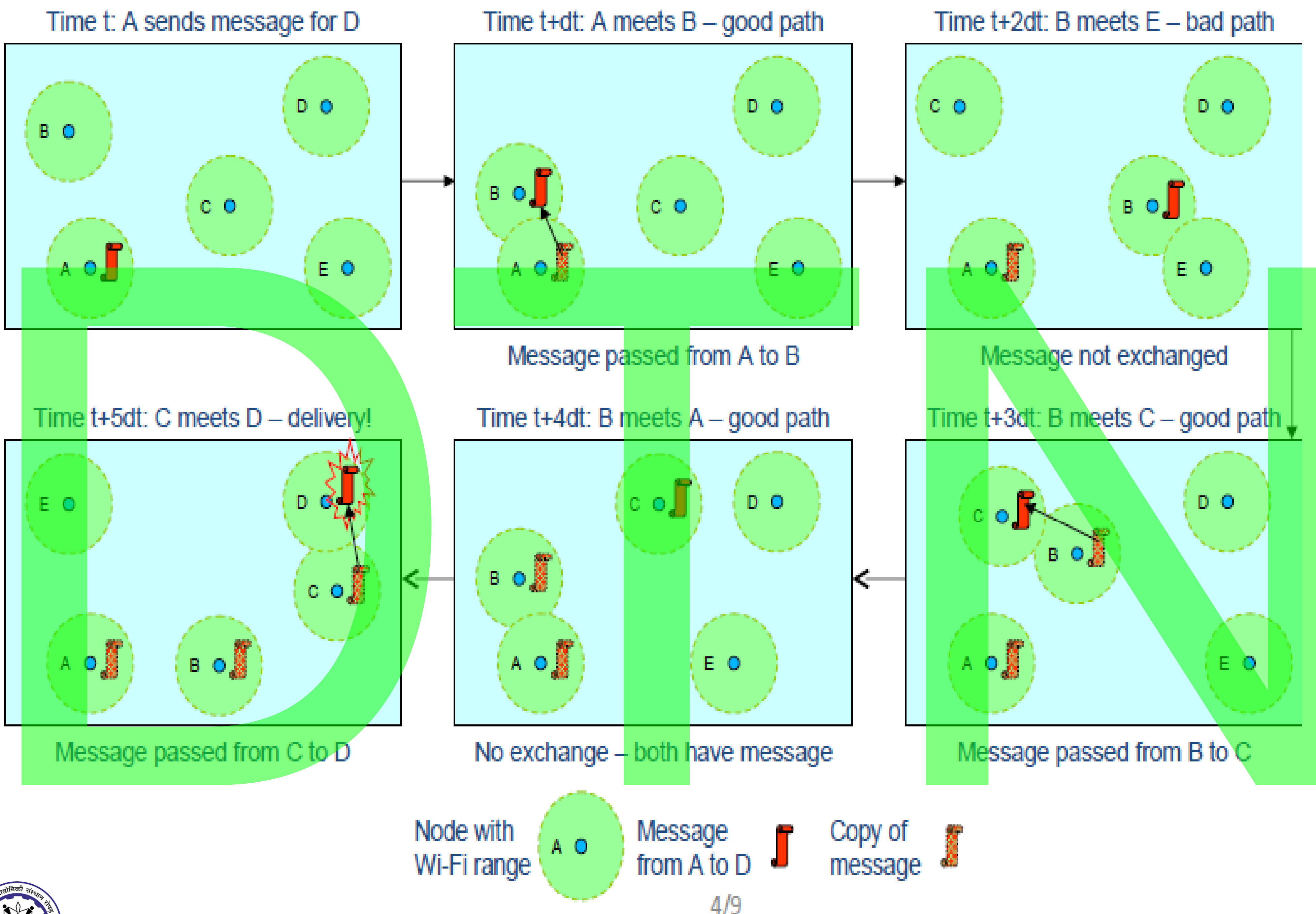
Time t: A sends message for D
B
D
C
A
E
Time t+dt: A meets B – good path
Message passed from A to B
Time t+2dt: B meets E – bad path
Message not exchanged
Time t+3dt: B meets C – good path
Message passed from B to C
Time t+4dt: B meets A – good path
No exchange – both have message
Time t+5dt: C meets D – delivery!
Message passed from C to D
Node with
Wi-Fi range
Message
from A to D
Copy of
message
4/9

# Modeling the Mobility Pattern

Every node maintains a set of Delivery Predictabilities (DPs) for nodes it has encountered (reasonably) recently

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- DP before/after encounter: $P_A(B)_{old}$ / $P_A(B)_{new}$
- DP for node B stored in node A: $P_A(B)$

The proposed values of $P_{encounter}$ = 0.75
B=0.25 and γ = 0.998

Node A encounter node B

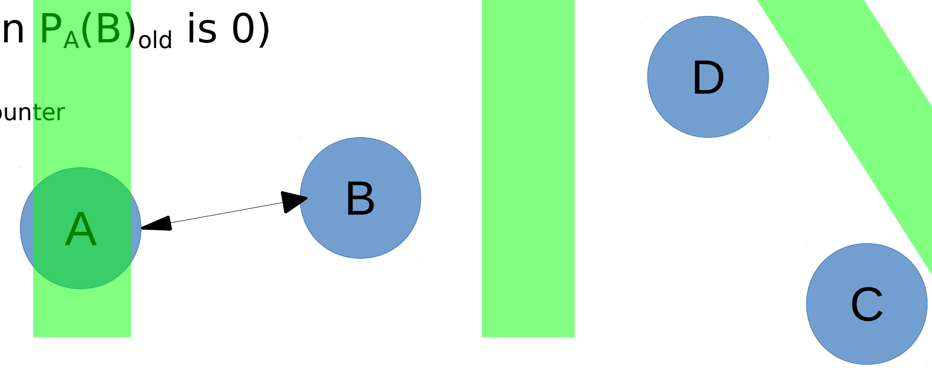
Initially, $P_A(B)_{old}$ is 0

- $P_A(B)_{new} = 0.5$ (on first encounter, when $P_A(B)_{old}$ is 0)
- $P_A(B)_{new} = P_A(B)_{old} + (1 - P_A(B)_{old}) * P_{encounter}$

If B encounters A in past, calculate new $P_A(B)_{new}$

$DP_A$

| Nodes | $DP_A$ |
|---|---|
| B | |
| C | |
| D | |



# Delivery Predictabilities

Basic DP Evolution Equations in node A when it meets node B

- Direct encounter: DP for encountered node increases at each encounter
  - $P_A(B)_{new} = 0.5$ [on first encounter – when $P_A(B)_{old}$ is 0]
  - don’t know whether there will be more meetings so ‘hedge our bets’..
  - $P_A(B)_{new} = P_A(B)_{old} + (1 - P_A(B)_{old}) * P_{encounter}$ [subsequent encounters]
- Decay over time: All DPs are decreased if the node hasn’t been encountered
  - $P_A(B)new = P_A(B)old * \gamma^K$ [K is number of time units since last decay]
  - If $P_A(B)$ gets very small, set it to 0 and treat next encounter (if any) as first
- Transitive rule: If B is a good path to C and A meets B frequently then nodes that meet A might want to give messages for C to node A
  - $P_A(C)_{new} = \max(P_A(C)_{old}, P_B(C), * P_A(B)_{new} * \beta)$ [β is a constant]
  - Encountered node (B) sends its set of DPs to A for use in the Transitive Rule

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# PROPHET

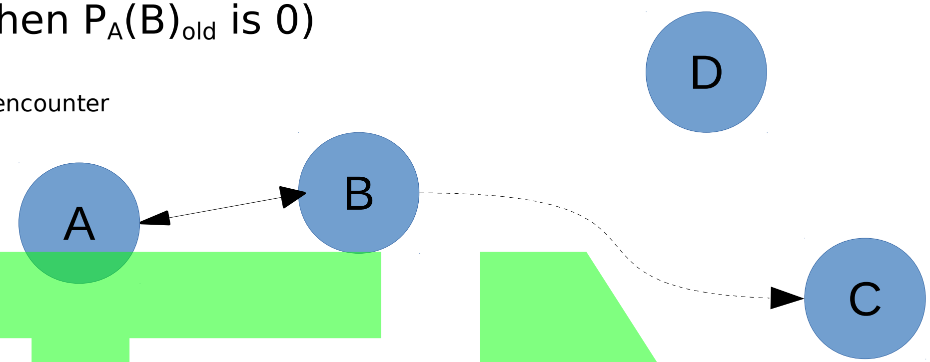
The proposed values of $P_{encounter}$ = 0.75
$\beta$=0.25 and $\gamma$ = 0.998

Node A meets node B

Initially, $P_A(B)_{old}$ is 0

- $P_A(B)_{new}$ = 0.5 (on first encounter, when $P_A(B)_{old}$ is 0)
- $P_A(B)_{new} = P_A(B)_{old} + (1 - P_A(B)_{old}) * P_{encounter}$

If B encounters A in past, calculate new $P_A(B)_{new}$




$DP_A$

| Nodes | $DP_A$ |
|---|---|
| B | |
| C | |
| D | |

- All DPs are decreased if the node hasn't been encountered
  - $P_A(D)new = P_A(D)old * \gamma^K$ [k denotes the number of time units expired since the last update of this predictability]
  - If $P_A(D)$ is very small, set it to zero.

Example: Let $P(A, D)_{old}$ = 0.5, and the pair of nodes does not have any subsequent encounter. If a single time unit comprises 60 s, then after two time units, the updated delivery predictability would be $P(A, D)_{new} = P(A, D)_{old} \times \gamma^2 = 0.5 \times 0.998^2 = 0.498$.

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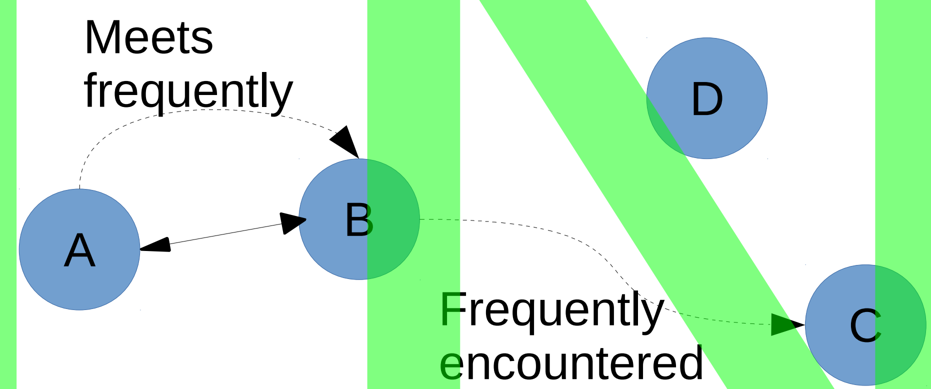
# PROPHET

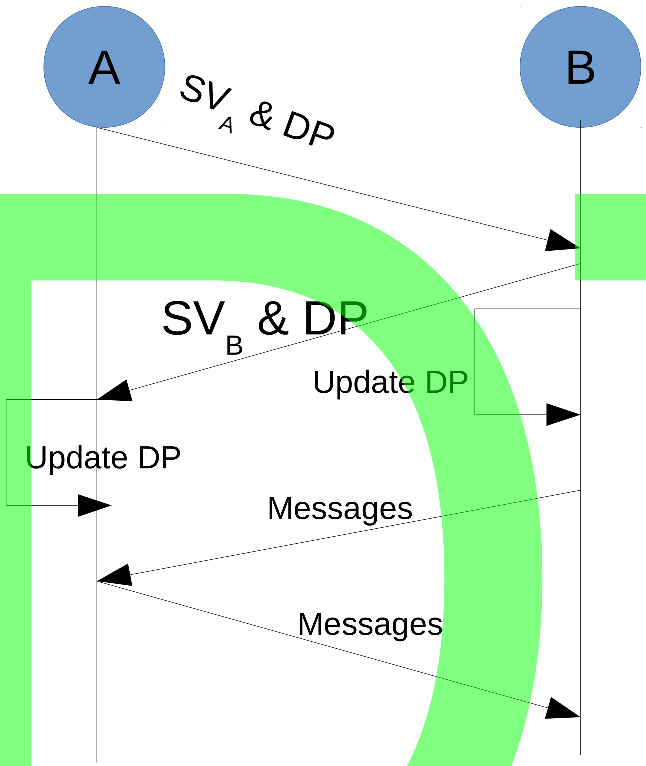
- Transitive rule: If B is a good path to C and A meets B frequently then nodes that meet A might want to give messages for C from node A
  - $P_A(C)_{new} = \max(P_A(C)_{old}, P_B(C), * P_A(B)_{new} * \beta)$ [β=0.25 is a constant]
  - Encountered node (B) sends its set of DPs to A for use in the Transitive Rule

$DP_A$

| Nodes | $DP_A$ |
|---|---|
| B | |
| C | |
| D | |



# PROPHET

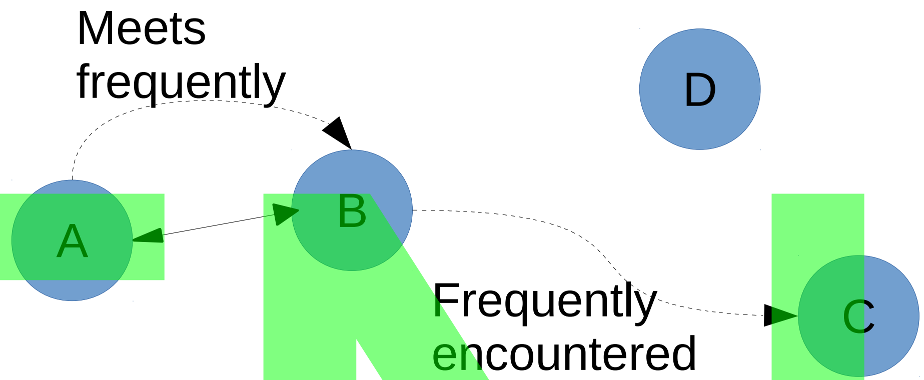



$DP_A$

| Nodes | $DP_A$ |
|---|---|
| B | |
| C | |
| D | |

$SV_A$

| Messages | Destination |
|---|---|
| m1 | C |
| m4 | D |
| m8 | D |




Let's consider m1 is not present in $SV_B$.

If $P_{(B, C)} > P_{(A, C)}$, then Node A forwards m1 to Node B.

If $P_{(B, D)} > P_{(A, D)}$, then Node A forwards m4 to Node B, otherwise Node A would keep m4 in its buffer.

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# Spray and Wait routing

- *Spray and Wait* routing “sprays” a number of copies into the network, and then “waits” till one of these nodes meets the destination.

T. Spyropoulos, K. Psounis, and C. S. Raghavendra, “Spray and wait: an efficient routing scheme for intermittently connected mobile networks,” in Proceedings of the 2005 ACM SIGCOMM workshop on Delay-tolerant networking (WDTN ’05). New York, NY, USA: ACM, 2005, pp. 252–259.

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# Spray and Wait routing (Cont.)

- Spray and Wait routing consists of the following two phases:
  - *Spray phase:* For every message originating at a source node, L message copies are initially spread – forwarded by the source and possibly other nodes receiving a copy – to L distinct "relays"
  - *Wait phase:* If the destination is not found in the spraying phase, each of the L nodes carrying a message copy performs direct transmission (i.e. will forward the message only to its destination)

- This does not tell us how the L copies of a message are to be spread initially. So an improvement over Spray & Wait is Binary Spray & Wait

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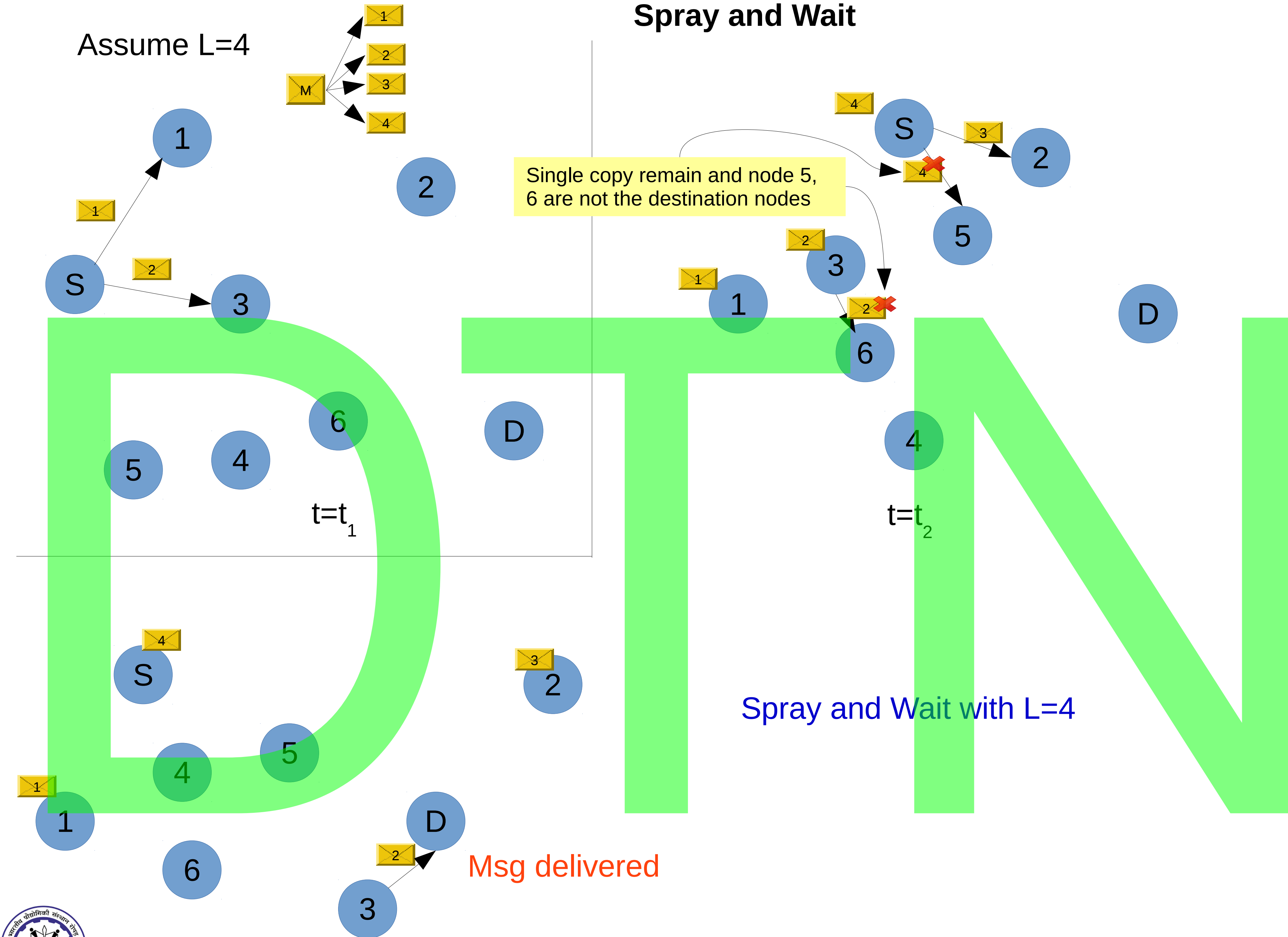
## Spray and Wait




Spray and Wait with L=4

# Binary Spray and Wait routing

- Binary Spray & Wait:
  - The source of a message initially starts with L copies; any node A that has $n > 1$ message copies, and encounters another node B with no copies, hands over to B, $\lfloor n/2 \rfloor$ and keeps $\lceil n/2 \rceil$ for itself; when it is left with only one copy, it switches to direct transmission

In binary SnW, the source node initially has L copies of a given message. Now consider any node—whether the source or a relay—that has n copies of the message, $L \geq n > 1$. If one such node encounters another node having no copy of the message, the latter node is given $\lfloor n/2 \rfloor$ copies of the message, while the former itself retains $\lceil n/2 \rceil$ copies.

It has been shown that the binary spraying technique is optimum and results in minimum expected delay among all Spray and Wait routing mechanisms.

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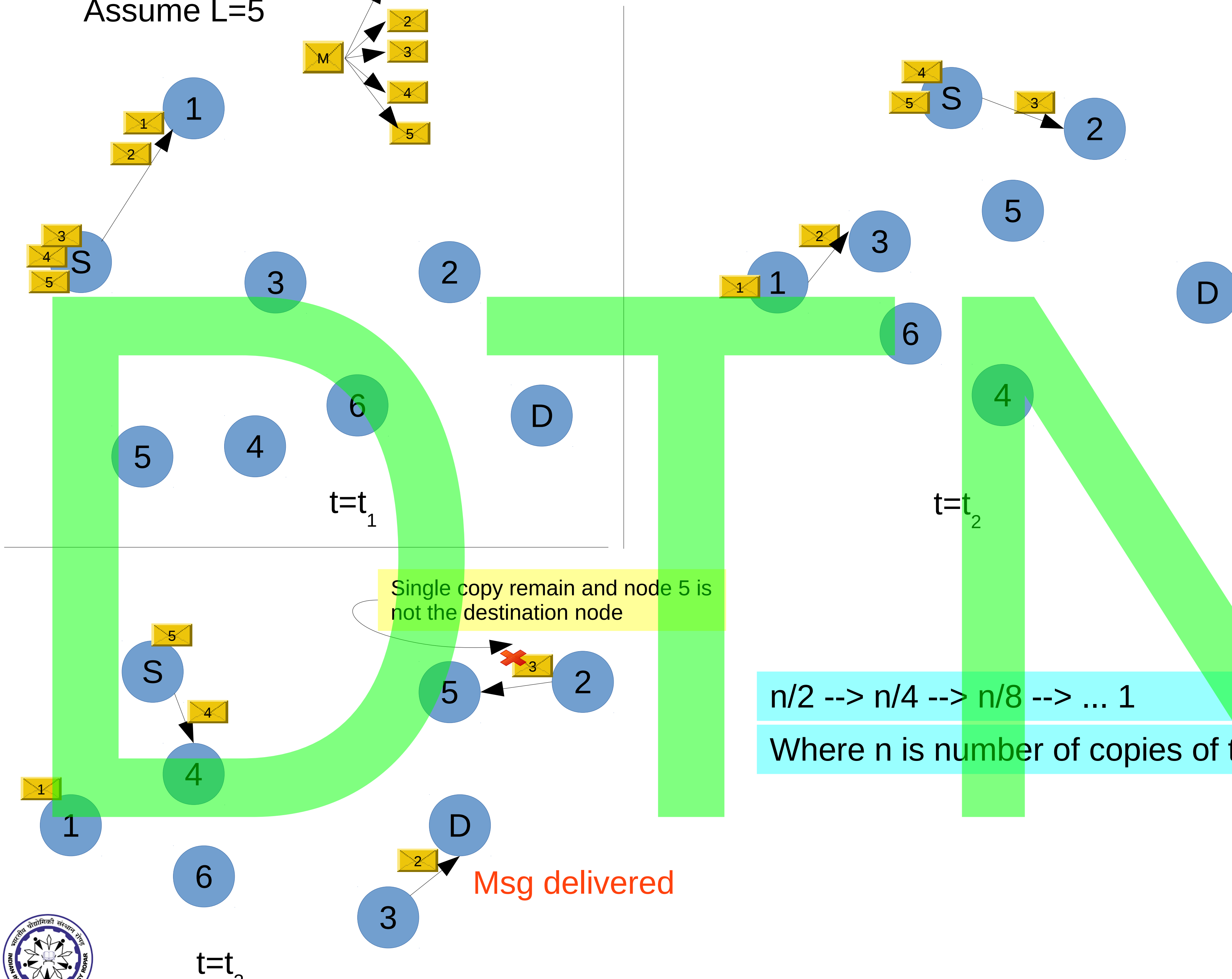
# Binary Spray and Wait




n/2 --> n/4 --> n/8 --> ... 1

Where n is number of copies of the msg

# Spray and Focus

T. Spyropoulos, K. Psounis, and C. Raghavendra, “Spray and focus: Efficient mobility-assisted routing for heterogeneous and correlated mobility,” in Fifth Annual IEEE International Conference on Pervasive Computing and Communications Workshops, 2007. PerCom Workshops ’07., White Plains, NY, March 2007, pp. 79–85.

**Spray phase:** Similar to SnW. However, instead of the wait phase

**Focus phase:** Rather than waiting for the destination to be encountered, each relay can forward its copy to a potentially more appropriate relay, using a carefully designed utility based scheme.

Wait phase (SnW): Direct transmission to Destination node
Here the forwarding decision is based on a utility.

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# Spray and Focus

Definition 2.2 (Single-copy Utility-based Routing) Let every node i maintain a utility value $U_i$ (j) for every other node j in the network. Then, a node A forwards to another node B a message destined to a node D, if and only if $U_B(D) > U_A(D) + U_{th}$, where $U_{th}$ (utility threshold) is a parameter of the algorithm.

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