Buffer Aware Routing in Interplanetary Ad Hoc Network

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Presentation Outline

Introduction to IPAN

- An Interplanetary Ad hoc Network (IPAN) is an Ad hoc wireless network among communication nodes (e.g. spacecrafts and rovers) located on planets and satellites in space, [9] and [10].

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- IPAN is a specific case of Delay Tolerant Network (DTN).
- Nodes in such networks are resource constrained in terms of storage, energy and data transmission bandwidth.

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   - Given higher priority over other traffics and
   - Resources are reserved for it.
   - e.g. traffic of command, control and navigation system.
2. Best effort traffic
   - Not sensitive to delay.
   - No special resources are reserved for it.
   - e.g. data of photographs and environmental information of outer space.

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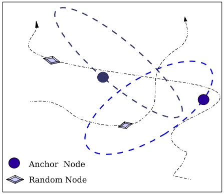
3. Implementation of store-and-forward *DTN architecture*, *node mobility generator* and the *contact oracle* in ns2.
4. Estimation of required buffer size as a function of network parameters.

Network model for IPAN



1. Anchor node:
   - Fixed orbits of movements
   - Have greater resources compared to random nodes
   - e.g. Nodes on planets and natural satellites

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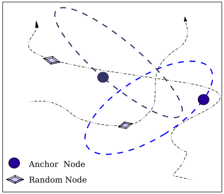

1. Anchor node:
   - Fixed orbits of movements
   - Have greater resources compared to random nodes
   - e.g. Nodes on planets and natural satellites
2. Random node:
   - Movement patterns are not deterministic
   - Resource constraint
   - e.g. Spacecrafts and small vehicles on planet satellites

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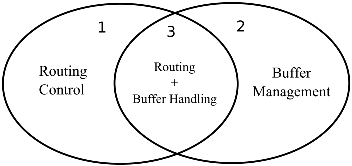
- Propose a protocol to route best effort traffic for IPANs, where communicating entities are of different natures.
- Protocol should achieve higher delivery ratio by taking buffer into consideration, using minimum network knowledge and minimum protocol overhead.

Approach to the solution

Routing strategy of the BARPIN:



1. Generation and dissemination of control information to the neighbor nodes.
2. Deals with the condition of buffer overflow at the congested node.
3. The packet forwarding logic is implemented.

1. Routing Control

When two nodes encounter they exchange following information:

1. Their future contact probability (*fcp*) value table
2. Buffer occupancies (B_f)
3. Average encounter time (δ)
4. Anchor nodes send their next future contact time with other anchors, to their random neighbors

1. Routing Control

Calculation of fcp value [6]:
Let S be a set of all the nodes in the network, f_j^i be the *fcp* that node i has for node j, then

$$f_j^i = \begin{cases} (f_j^i)_{old}/2, & \text{if the node encountered} \neq j, \\ ((f_j^i)_{old}+1)/2, & \text{if the node encountered} = j, \end{cases} \qquad (1)$$

For node i at any instance of time, the following condition should always hold,

$$\sum_{j \in S} f_j^i = 1, \text{ for } i \neq j.$$

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Initially for all the nodes $i, j \in S$

$$f_j^i = \frac{1}{(|S|-1)}, \text{ for } i \neq j, \qquad (2)$$

2. Buffer Management

BARPIN proposes two policies to handle the buffer overflow:

1. **Buffer migration:** When there is a buffer overflow, then select one or more packets from the buffer and transfer them to any of the node in the neighborhood to make room for the new incoming packets.

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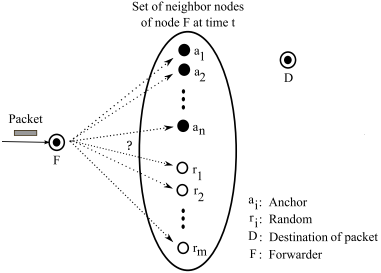
1. **Buffer migration:** When there is a buffer overflow, then select one or more packets from the buffer and transfer them to any of the node in the neighborhood to make room for the new incoming packets.
2. **Packet drop:** In this policy, when there is a buffer overflow, then it drops the oldest packet from the buffer to make the room.
   Our implementation uses this policy.

3. Buffer aware routing

BARPIN is a store-and-forward, one-hop-transfer protocol.



Key Question: "Which one will be the next hop node for the packet?"

3. Buffer aware routing . . .

Based on the type of forwarding node and the destination of the packet,

No.	Packet Forwarder	Destination
1	Random	Random
2	Random	Anchor
3	Anchor	Random
4	Anchor	Anchor

Table: Possible packet forwarding cases

3. Buffer aware routing . . .

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Table: Possible packet forwarding cases

Each of the above four cases contain following three sub cases:

1. Only random nodes in the neighborhood
2. Only anchor nodes in the neighborhood
3. Both anchor and random nodes in the neighborhood

3. Buffer aware routing . . .

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- Only *fcp* and B_f values are known for neighbors.

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- Forwarding node should select a node such that chances of packet getting delivered increases and packet getting dropped decreases.
- BARPIN defines likelihood P_{LH}, of a node to deliver the packet to its destination, as the function of both, *fcp* and B_f as follows:

$$P_{LH} = \frac{fcp}{1 + B_f}. \quad (3)$$

3. Buffer aware routing . . .

Algorithm-1: Selection of most favorable random node

1. Let R be a set of all the random nodes in the current neighborhood of the packet forwarding node and let $m = |R|$, where $|R|$ is the cardinality of set R. For each $r_i \in R$, where $i = 1, 2, \ldots, m$; calculate P_{LHi} using (3).
2. If the average encounter rate of node r_i is δ_i and if r_{fn} is the most favorable random node in the current neighborhood then

$$r_{fn} = \{r_i |\ (P_{LHi}/\delta_i) \text{ is maximum, for } \ i = 1, 2, \ldots, m\}$$

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- BARPIN defines an effective time required for the node to meet the destination of the packet as the function of both, the actual time $t^{'}$ and B_f.
- If the effective time a node i will take to reach the destination is $t_i^{'}$ and B_{fi} is the buffer occupancy of the node i then, $t_i^{'}$ is given as:

$$t_i^{'} = t_i(1 + B_{fi}). \tag{4}$$

Algorithm-2: Selection of most favorable anchor node

1. Let A be a set of all the anchor nodes in the current neighborhood of the packet forwarding node and let $n = |A|$, where $|A|$ is the cardinality of set A. For each $a_i \in A$, where $i = 1, 2, \ \ldots \ , n$; calculate $t_i^{'}$ using (4).
2. If a_{best} is the most favorable anchor node in the current neighborhood then

$$a_{best} = \{a_i | \ t_i^{'} \text{ is minimum, for } \ i = 1, 2, \ \ldots \ , n\}$$

3. Buffer aware routing . . .

Both anchor and random nodes in the neighborhood:

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- Packet forwarding node finds out the most favorable random nodes from the neighborhood, using Algorithm-1.
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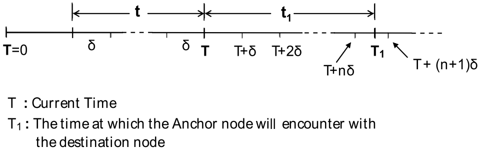

Figure: Comparing anchor and random nodes with respect to time for next hop node selection .

3. Buffer aware routing . . .

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- If the buffer occupancy of the random node r_{fn} is B_{fR}, then similar to equation (3), the likelihood of the node r_{fn} can be given as

$$P_n^{'} = \frac{P_n}{(1 + B_{fR})}. \quad (5)$$

3. Buffer aware routing . . .

Both anchor and random nodes in the neighborhood:
Selection of the next hop should ideally try to:

(C1) maximize the probability of delivery of the packet to its destination and

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The decision of the next hop node with respect to above two objectives can be made using following inequality :

$$\left(\frac{P_n'}{\alpha \left(\frac{n\delta}{t_1'} \right)} \right) > \varepsilon \tag{6}$$

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- The higher the value of ε more we prefer the anchor node over the random node.
  In that case one would go for random node only when δ for that node is very low and the value of $P_n^{'}$ is high.

3. Buffer aware routing . . .

Both anchor and random nodes in the neighborhood:

A Case: Take a case where $\delta \geq t_1^{'}$,

- Set $\alpha = \varepsilon = 1$ for simplicity, then by equation (6), the following must hold.

$$P_n^{'} > \left(\frac{n\delta}{t_1^{'}} \right)$$

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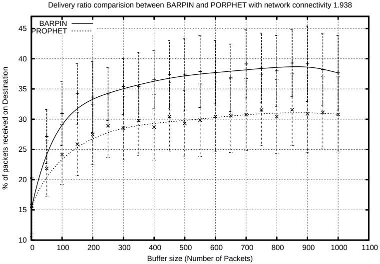
- but the probability value can never be greater than 1.
- So such an inequality never holds, and therefore never go for random node in this case.

Simulation Results

Varying field size:

(a) When Destination is a random node



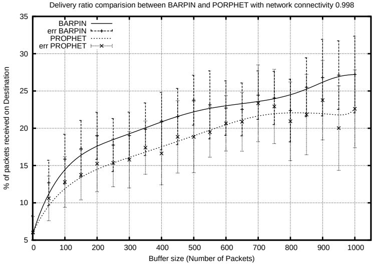
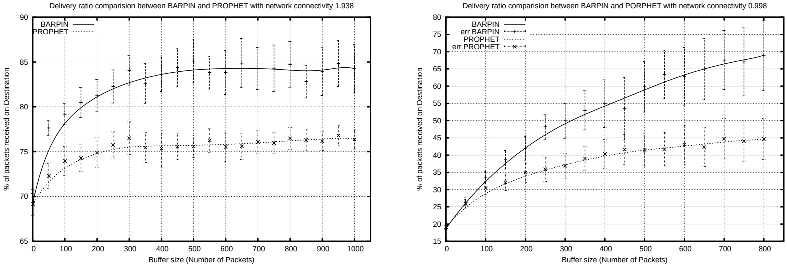


Figure: Graphs for different field sizes when BA=3BR and Rate 10pkt/sec

Simulation Results . . .

Varying field size:

(b) When Destination is an anchor node



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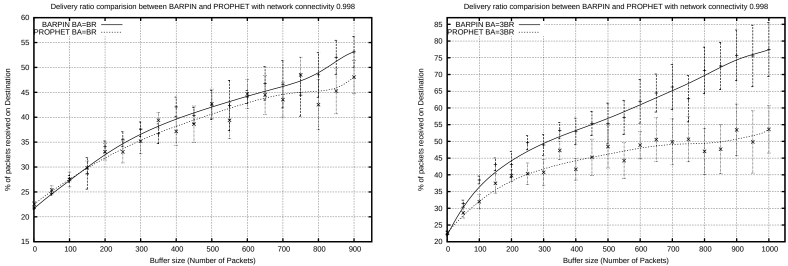
Simulation Results . . .

Varying anchor node to random node buffer size ratio:



(a) Buffer size for $B_A = B_R$ (b) Buffer size for $B_A = 3 \times B_R$

Figure: Graphs when field size is 2000x2000 and Rate 10pkt/sec

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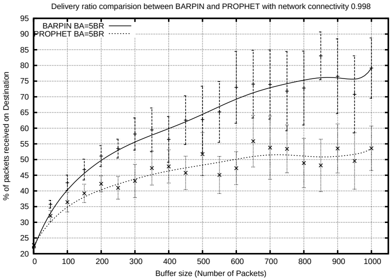
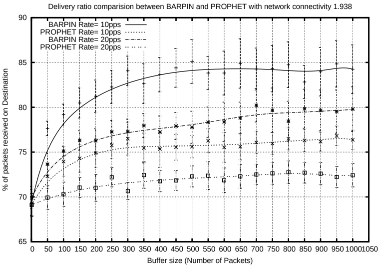


(a) Buffer size for $B_A = 5 \times B_R$

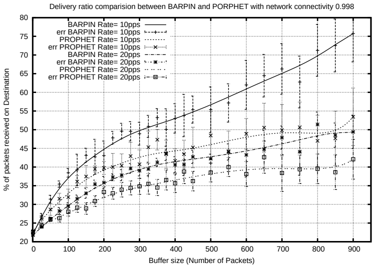
Figure: Graphs when field size is 2000x2000 and Rate 10pkt/sec

Simulation Results . . .

Varying Data Rate:



(a) field size 1500 $\times$ 1500



(b) field size 2000 $\times$ 2000

Figure: Graphs when BA=3BR and Rate 10pkt/sec

Estimation of node buffer size

Let T_R be a total traffic rate of the network.

Let $\bar{\tau}$ be an average inter encounter time between any two nodes in the network.

Then the minimum required buffer size for the node to avoid packet drop is,

$$B = \gamma \times T_R \times \bar{\tau}. \quad (7)$$

Here γ is the *"encounter diversity factor"* of the network, which signifies the fraction of total number of nodes encountered by the given node.

Conclusion

- We have proposed BARPIN, an effective buffer aware probabilistic routing protocol for Interplanetary ad hoc Networks, which uses knowledge about the connectivity and the resources consumption of the nodes to make an efficient routing decision.
- For all the various network conditions, BARPIN offers higher packet delivery ratio than the PROPHET due to its buffer awareness in selection of next hop node.

Future work

1. Implementation of protocol independent buffer management policy, called "Buffer migration".
2. One can improve the buffer function to make it more realistic.
3. The existing protocol can be studied over other performance measures like delay, bandwidth utilization etc. to test it performance in different conditions.

Thank you

References

[1] Abdelmajid Khelil, *"Mobility-Aware Buffering for Delay-Tolerant Ad Hoc Broadcasting"*, SPECTS, July 2006.

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[5] Evan Jones, Lily Li, Paul Warde, *"Practical Routing in Delay-Tolerant Networks"* Workshop, SIGCOMM August 2005.

[6] John Burgess, Brian Gallagher, David Jensen, Brian Neil Levine, *"MaxProp: Routing for Vehicle-Based Disruption-Tolerant Networks"* Proceedings IEEE INFOCOM, April 2006.

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[8] Padma Mundur, Sookyoung Lee, Matthew Seligman, Seligman, *"Routing for Data Delivery in Dynamic Networks"*, MILCOM 2006.

[9] InterPlaNetary Internet Project, `http://www.ipnsig.org/home.htm`.

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Default parameters of the simulation

Parameter	Value
Simulation field size	$2000 \times 2000\ m^2$
Average node degree	0.998
Number of nodes	15
Simulation time	1000 sec
Data rate	10 packets/sec (or pps)
Packet size	1000 bytes
Application time	From 5 to 505 sec
Background traffic	Two sources continuously transmit packets with data rate 10 packets/sec from 10 to 900 sec
Buffer timeout period	500 sec
Anchor vs Random node's buffer ratio	Anchor node's buffer size $= 3\times$Random node's buffer size
α	2.0
ε	1.0

Table: Default parameters of the simulation

Overhead of the BARPIN over PROPHET

- In PROPHET, nodes exchange the following table as control information:

Node ID	DL Value

- In BARPIN,
  - a Nodes exchange the following table as control information:

Node ID	*fcp* Value	B_f	δ

  - b When any anchor node meets any random node, then it send its next future contact time with other anchors to the random node.
- Algorithm used to select next hop node in BARPIN is more complex than the one used in PROPHET.

[A. Lindgren, A. Doria, O. Schelen, *"Probabilistic Routing in Intermittently Connected Networks"*, In Proceedings of the The First International Workshop on Service Assurance with Partial and Intermittent Resources(SAPIR 2004), August 2004.]

Related work

No.	Protocol	Protocol type	Buffer management policy
1	Practical Routing in DTN [5]	Deterministic	Used two buffer management policies: drop tail and hop-by-hop flow control.
2	MaxProp [6]	Deterministic	Scheduled the packets for transmission and dropping. Used acknowledgements, remove copies of packets delivered to the destination.
3	mBFS [8]	Deterministic	Used storage domain concept (few connected nodes act as a single storage unit) to optimize buffer utilization of nodes.

Related work . . .

No.	Protocol	Protocol type	Buffer management policy
4	NoCostDrop [2]	Packet flooding algorithm	Introduced three criteria to drop the packet when there is a buffer overflow.
5	Storage Routing [7]	Buffer management protocol	Introduced a protocol independent buffer management scheme called "Storage Routing" to deal with congestion.
6	Mobility aware buffering[1]	Probabilistic flooding	Based on the mobility patterns of the nodes, protocol select a node from the group to store the packet when there is a network partition.

Related work . . .

- All these protocols are based on the assumption that all the nodes are homogenous and of similar characteristics.
- Protocols proposed in [5], [6] and [8] required complete knowledge of topology to make routing decision.
- Protocols proposed in [1] and [2] are based on packet flooding algorithms.
- Interrogation based protocols proposed in [3] and [4] assume that all the nodes in network move in either elliptical or circular orbits and they do extensive messaging as part of interrogation phase.