# A Message Ferrying Approach for Data Delivery in Sparse Mobile Ad Hoc Networks

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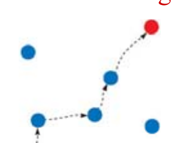
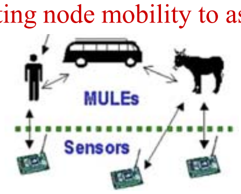
# How to deliver data in sparse networks

- Ad-hoc routing (increase the radio strength to remove partitions from the network)



- Data MULEs (use existing node mobility to assist data delivery)




- *Message Ferrying* (add nodes with controllable mobility to the network)

## Outline

- Variations of Message Ferrying and Applications
- Two variations in detail
  - Operation of nodes
  - Trajectory control of nodes
- Performance Evaluation
- Conclusion



## Applications

- Crisis-driven
  - Battlefield
  - Disaster
  - Message ferrying fills in for destroyed or nonexistent infrastructure
- Geography-driven
  - Wide area sensing and surveillance
  - Sparse networks
  - e.g. ZebraNet, DataMULE
- Cost-driven
  - Provide low cost internet connectivity between villages
  - e.g. DakNet
- Service-driven
  - privacy

## Two Variations of Message ferrying

- The network has two types of nodes: ferries and endpoints
- Both types of nodes are mobile
- The paper considers two variations of message ferrying, based on the mobility of ferry and endpoint nodes
- *Node-Initiated MF (NIMF)*
  - Ferry nodes follow fixed path
  - Endpoint nodes move close to a ferry to initiate communication
- *Ferry-Initiated MF (FIMF)*
  - Ferries move proactively to meet endpoint nodes
  - Endpoint nodes transmit long range request message to let near by ferries know that it needs service

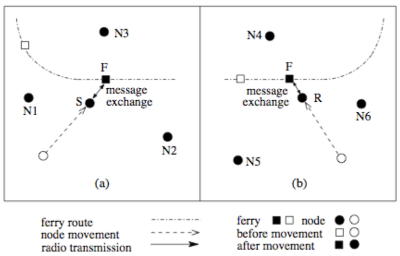


## Two Types of Mobility

- *Task-oriented mobility*
  - Ferry or endpoint mobility is determined for non-messaging reasons
  - e.g. the ferry is a campus bus
- *Messaging-oriented mobility*
  - Ferry or endpoint mobility is controlled to improve the performance of messaging
  - e.g. robots in disaster area

## NIMF (Node-Initiated Message Ferry) Operations

- S moves to reach F and transfers message
- R moves to reach F and receive message




```
detour: whether the node is detouring;
mode: which mode the node is in;
1. WORKING mode
    detour = FALSE;
    IF Trajectory Control indicates time to go to the ferry,
        detour = TRUE;
        mode = GO_TO_FERRY;
    On reception of a Hello message from the ferry:
        mode = SEND/RECV;
2. GO_TO_FERRY mode
    Calculate a shortest path to meet the ferry;
    Move toward the ferry;
    On reception of a Hello message from the ferry:
        mode = SEND/RECV;
3. SEND/RECV mode
    Exchange messages with the ferry;
    On finish of message exchange or the ferry is out of range:
        IF detour is TRUE,
            mode = GO_TO_WORK;
        ELSE
            mode = WORKING;
4. GO_TO_WORK mode
    Move back to node's location prior to the detour;
    On return to the prior location:
        mode = WORKING;
    On reception of a Hello message from the ferry:
        mode = SEND/RECV;
```



## Node Trajectory Control

- Goal: minimize message drops while reducing the negative impact of proactive movement
- Message drops are caused by message timeouts and buffer overflow at endpoint nodes, and because of timeouts at ferries
- $D_i^n(t)$ := node i's own message drop rate during time slot t
- $D_i^f(t)$ := the drop rate in the ferry for destination i during slot t
- $t_d$ := the time slot in which the node is expected to meet the ferry after proactive movement
- If the node chooses not to meet the ferry at time $t_d$, it will incur message drops at a rate $D_i(t_d)=D_i^n(t_d)+D_i^f(t_d)$
- $\alpha$ := average time between a node's visit to the ferry
- T := the message timeout value
- $m_i(t_d+\alpha-T)$ := number of messages generated that are lost due to timeout
- $G_i^n$ := message generation rate in node i
- $G_i^f$ := message arrival rate in the ferry
- Finally, make decision to move proactively based on threshold:
- $(D_i(t_d) + m_i(t_d+ \alpha -T))/(G_i^n + G_i^f)\geq\beta$ (i.e. avoid detour when drop rate is low relative to message generation rate)

## What is the cost of a detour?

- It is application specific
- More recent work factors in energy cost of mobility
- Here it is simply *work time percentage (WTP)*: the percentage of time a node is free to work on assigned tasks (i.e. the node is not making a detour for message transmission or reception)



## How a node computes its drop rate

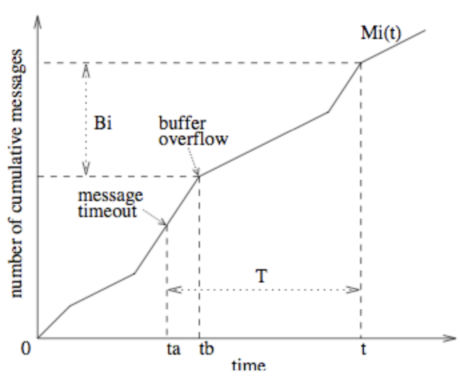
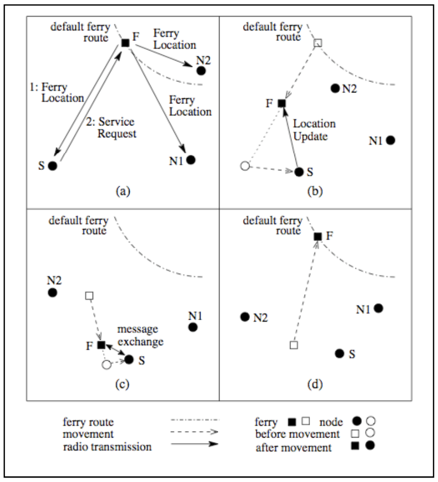



**Figure 5: An example of message drop rate computation in node $i$. Messages dropped during slot $t$ would have arrived at node $i$ during either slot $t_a$ or slot $t_b$ ($t_b$ in this example).**

## FIMF (Ferry-Initiated Message Ferry) Operations




*H*: the set of requesting nodes;
*P*: the ferry route in the `WORKING` mode;
*mode*: which mode the node is in;
1. `IDLE` mode
    Set *H* to be an empty set;
    Move on a default route;
    Broadcast location messages periodically;
    On reception of a `Service_Request` message from node *i*:
        Add *i* to *H*;
        Compute new ferry route *P*;
        *mode* = `WORKING`;
    On reception of messages from a node:
        Exchange messages with the node;
2. `WORKING` mode
    Move along route *P*;
    Broadcast location messages periodically;
    On reception of a Request/Update message from node *i*:
        Add *i* to *H*;
        Compute new ferry route *P*;
    On finish of transmission or meeting with node *j*:
        Remove *j* from *H*;
        IF *H* is not empty,
            Compute new ferry route *P*;
        ELSE
            *mode* = `IDLE`;
    On reception of messages from a node:
        Exchange messages with the node;

In FIMF the ferry moves to intercept a node that makes a service request. The service request is made using a high power radio on the node.



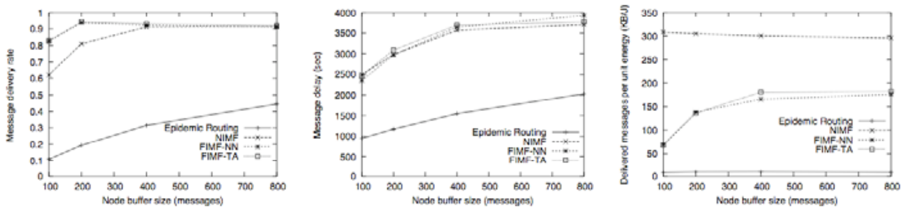
## Ferry Trajectory Control

- Suppose that the ferry has a request buffer H
- What is the expected number of message drops for a route that services all of the nodes in H in some particular order?
- k := number of requesting nodes in H
- $s_i$ := latency to reach node i
- Expected message drops is:

$$D^P = \sum_{i=1}^{k} \sum_{l=0}^{s_i} (D_i^n(t_0 + l) + D_i^f(t_0 + l))$$

- The ferry route problem is finding a route that minimizes $D^P$
- The problem becomes Minimum Latency Problem (MLP) which is NP-hard, so heuristics are used

## Simulation Results for Different Node Buffer Sizes




(a) Message delivery rate (b) Message delay (c) Delivered messages per unit energy

**Figure 9: Performance under different node buffer sizes.**

- NN and TA are two different heuristics used with FIMF
- Small buffer sizes reduce the performance of both NIMF and FIMF
- However, there is some point beyond which buffer size does have any effect on delivery rate, delay, and messages per unit energy
- NIMF is more energy efficient that FIMF



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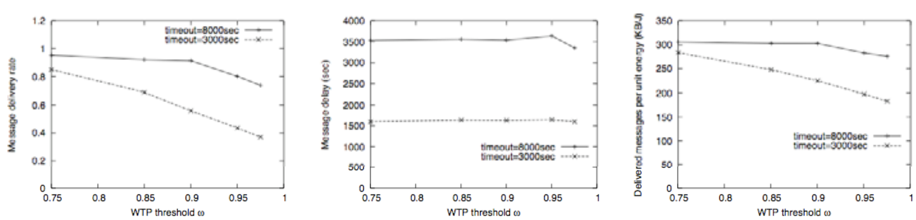
## Simulation Results for Different Work Time Percentage Thresholds




(a) Message delivery rate (b) Message delay (c) Delivered messages per unit energy

**Figure 10: Performance of the NIMF scheme under different WTP thresholds.**

- More time at work reduces delivery rate and messages per unit energy
- Delay is not affected because node batches messages and tries to avoid visit with ferry as much as possible



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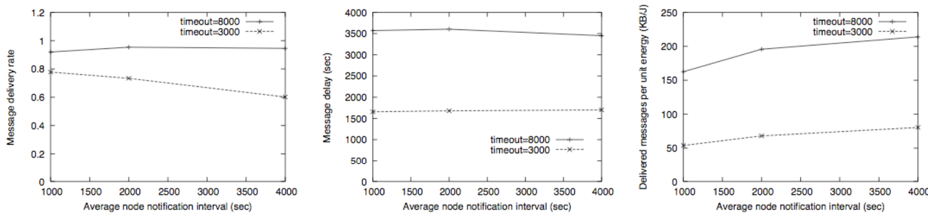
## Simulation Results for Different NMR Thresholds



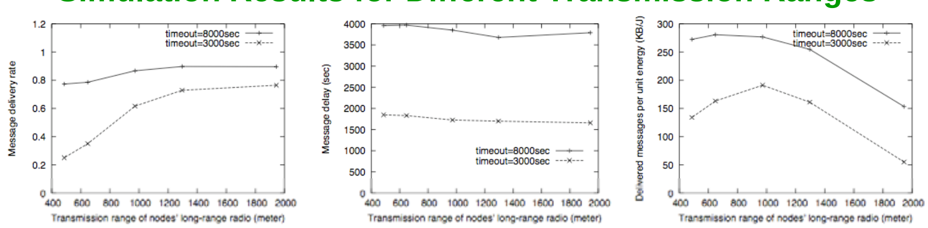

(a) Message delivery rate (b) Message delay (c) Delivered messages per unit energy

**Figure 11: Performance of the FIMF scheme under different NMR thresholds.**

- *Notification Message Rate (NMR)* is rate of notifications sent by a ferry in FIMF
- For a large timeout (8000) nodes can buffer longer so message delivery rate is not affect as much by NMR as it is with smaller timeouts (3000)
- Message delay is mostly independent of NMR
- Messages per unit energy increases with increased NMR



## Simulation Results for Different Transmission Ranges




(a) Message delivery rate (b) Message delay (c) Delivered messages per unit energy

**Figure 12: Performance of the FIMF scheme under different transmission ranges.**

- In FIMF a node needs long-rage radios to inform a ferry that it requires service
- Having a longer radio range can increase deliver rate to a point
- Message delay is again unaffected
- Messages per unit energy increases at first because the node is able to attract near by ferries, but eventually the energy cost of the high power messages requests and the diminishing returns of contacting far away ferries overcomes the energy savings

## Conclusions

- The work considers only a single ferry, future work could consider interaction with multiple ferries
- Does not consider effects of greedy node behavior trying to attract a ferry
- Does not account for energy cost of movement
- Only offers best-effort, can not guarantee that sensor readings from sensitive locations reach an access point by some time