Modelling of Control Overhead of MANET Protocols

– AODV –

Chunlei An

Institute of Communication Networks
Hamburg University of Technology
chunlei.an@tuhh.de

March 4. 2016

TUHH
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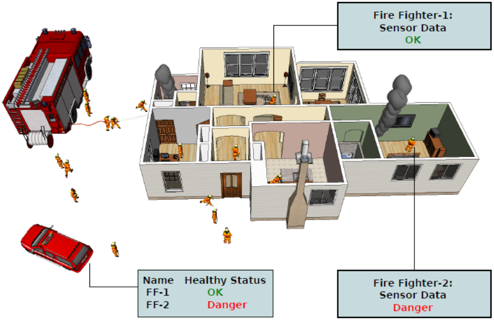
Fire Fighting Scenario

Fire fighters face different environments:



- On shift:
  - Work in teams, and teams are apart from each other → low (node) density
  - Active communication is essential → high traffic
- Off shift:
  - Structureless, stay rather close to each other → high (node) density
  - No active communication → low traffic

Problem Statement

- Communication in the firefighting scenario can be done using mobile ad hoc networks (MANETs)
- Two types of MANET routing protocols:
  - Proactive routing: route discovery and maintenance are independent of the data traffic
  - Reactive routing: on-demand route discovery
- Most suitable MANET routing schemes depend on application patterns, mobility and topology
- Application patterns and topology can dynamically change, therefore for different destinations different routing schemes are most suitable

Our Approach

- Create a hybrid and adaptive routing scheme, where in each node, some of the destinations are reached using reactive routing, and others are reached using proactive routing
- This can change over time, depending on mobility, topology or application changes
- Therefore a scheme needs to be defined to decide for which destination, which routing is the best
- This requires modeling of link stability and routing control overhead

Analytical Model for Routing Control Overhead

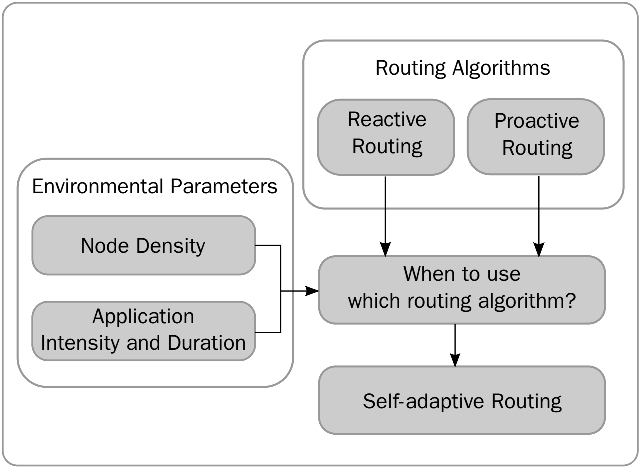
Goal of the model:

To find out the most suitable routing algorithm for a given environment, i.e., application characteristics and topology in terms of node density, so that the amount of the overall control overhead is minimized.

Two expectations on the model:

- Less dependent on global information obtained from massive simulations
  - Can work without running substantial simulations beforehand
  - Potential of being used for real time routing decision making
- Not too generic
  - Being able to capture characteristics of individual routing protocols
  - Giving in-depth understanding to a routing protocol

Analytical Model Structure



Most Important MANET Routing Protocols

Proactive routing

- Optimized Link State Routing (OLSR)
- Destination Sequenced Distance Vector Routing (DSDV)

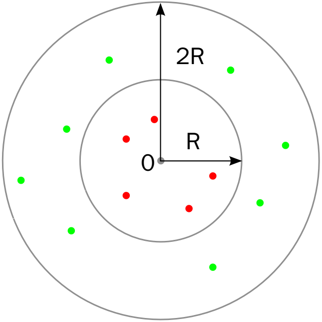
Reactive routing

- Ad hoc On-demand Distance Vector Routing (AODV)
- Dynamic Source Routing (DSR)
- Dynamic MANET On-demand Routing (DYMO)

State of the Art

1. L. Viennot *et al.*, "Analyzing Control Traffic Overhead versus Mobility and Data Traffic Activity in Mobile Ad-Hoc Network Protocols", 2004
   - Strong point: framework suitable for analyzing all type of MANET routing protocols
   - Weak point: many global information acquired from simulations, such as average node degree, average route creation rate per node, average path length, etc.
2. H. Xu *et al.*, "A Unified Analysis of Routing Protocols in MANETs", 2010
   - Strong point: sophisticated model covers many aspects, including mobility model, neighbor sensing, routing and MAC schemes
   - Weak point: very generic model, not designed for analyzing a specific routing protocol
3. D. Mahmood *et al.*, "Routing Load of Routing Discovery and Route Maintenance in Wireless Reactive Routing Protocols", 2012
   - Based on grid network topology, so the model is hard to be extended to random topologies

Network Model



1. The source node is denoted as 0
2. Each node's transmission range is identical, and is denoted as R
3. The number of nodes within a given area follows a Poisson distribution of the density λ
4. Within a given area, a node's coordinates (polar coordinates) follow an uniform distribution

Poisson Distribution

Given the node density λ, the probability of having k nodes in the area A is represented as:

$$\mathbf{P}(X = k) = \frac{(\lambda A)^k e^{-\lambda A}}{k!} \tag{1}$$

Accordingly, the probabilities of having no node and only 1 node:

$$\mathbf{P}(X = 0) = e^{-\lambda A} \tag{2}$$

$$\mathbf{P}(X = 1) = \lambda A e^{-\lambda A} \tag{3}$$

AODV Control Overhead

Assumption:

- No mobility → control overhead includes Route Request (RREQ) and Route Reply (RREP)

Notation:

- *Ni*: set of i-hop neighbors of the source node, where i = 1, 2, 3, ...

AODV route discovery procedure:

- To avoid flooding of the RREQ messages, the expending ring technique is used.
  - TTL[1] = 1, 3, 5, 7, ...

$$\mathbf{E}[|\text{RREQ}|] = \begin{cases} 1 & \text{if path length is 1} \\ 2 + \mathbf{E}[|N1|] + \mathbf{E}[|N2|] & \text{if path length is 2 or 3} \\ 3 + 2 \times \mathbf{E}[|N1|] & \\ \quad + 2 \times \mathbf{E}[|N2|] & \\ \quad + \mathbf{E}[|N3|] + \mathbf{E}[|N4|] & \text{if path length is 4 or 5} \end{cases} \tag{4}$$

[1] Time-To-Live

Number of 1-hop and 2-hop neighbors

Given the node density λ,

The expectation of the 1-hop neighbors:

$$\mathbf{E}[|N1|] = \pi R^2 \lambda \tag{5}$$

The area of the ring:

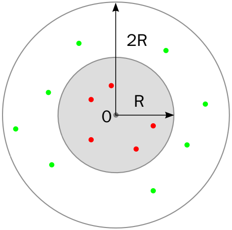
$$A_{ring} = \pi(2R)^2 - \pi R^2 \tag{6}$$

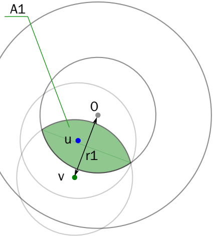
The probability that A1 contains at least one node:

$$\text{P(at least one node in A1(r1))} = 1 - e^{-\lambda A1(r1)} \tag{7}$$

The expectation of the 2-hop neighbors:

$$\mathbf{E}[|N2|] = A_{ring}\lambda \frac{1}{A_{ring}} \int_0^{2\pi} \int_R^{2R} \text{P(v(r1) is 2-hop)} r1 dr1 d\theta \tag{8}$$





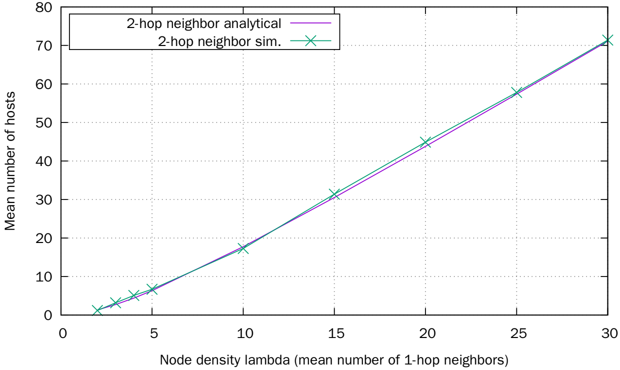
Model Validation: Setup

Scenario description:

	Analytical Model	Simulation
Traffic Model	Const Bit Rate (CBR)	
Radio Propagation Model	Unit Disc	Free Space
Playground	Circle with Radius 2R	

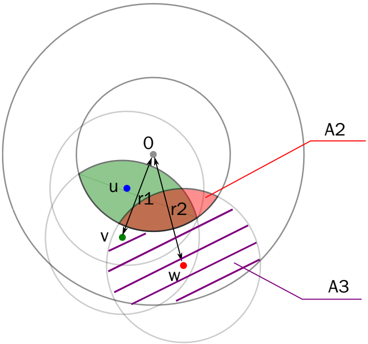
- Varying the node density λ
- Each simulation scenario is repeated 10 times, and only the average values are considered
- Euclidean distance is used to determine the neighbors of a node

Model Validation: 2-hop Neighbors



- The analytical results and the simulation results match nicely
- The number of the 2-hop neighbors increases almost linearly along with the increase of the node density

Number of 3-hop Neighbors



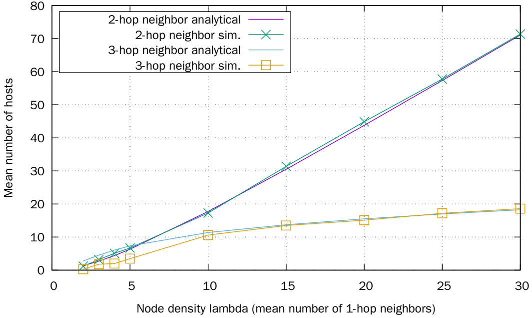
$$\mathbf{P}(\text{w(r2) is 3-hop}) = \mathbf{P}(\text{no node within A2(r2)}) * \mathbf{P}(\text{at least one node in A3(r2)}) * \int_R^{2R} \mathbf{P}(\text{v(r1) is 2-hop}) \text{r1} \, d\text{r1} \quad (9)$$

$$\mathbf{P}(\text{no node within A2(r2)}) = e^{-\lambda A2(r2)} \quad (10)$$

$$\mathbf{P}(\text{at least one node in A3(r2)}) = 1 - e^{-\lambda A3(r2)} \quad (11)$$

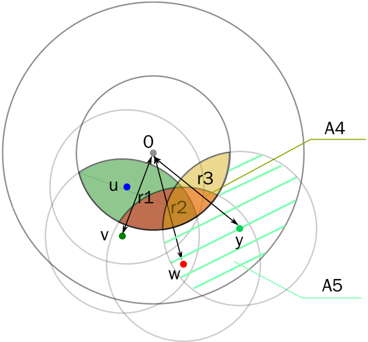
$$\mathbf{E}[|N3|] = A_{ring} \lambda \frac{1}{A_{ring}} \int_0^{2\pi} \int_R^{2R} \mathbf{P}(\text{w(r2) is 3-hop}) \text{r2} \, d\text{r2} \, d\theta \quad (12)$$

Model Validation: 3-hop Neighbors



- The analytical results match nicely the simulation results with high node density ($\lambda \geq 10$)
- The analytical model overestimates the number of the 3-hop neighbors when the node density is low ($\lambda < 10$)
- The number of the 3-hop neighbors does not increase as fast as the number of the 2-hop neighbors

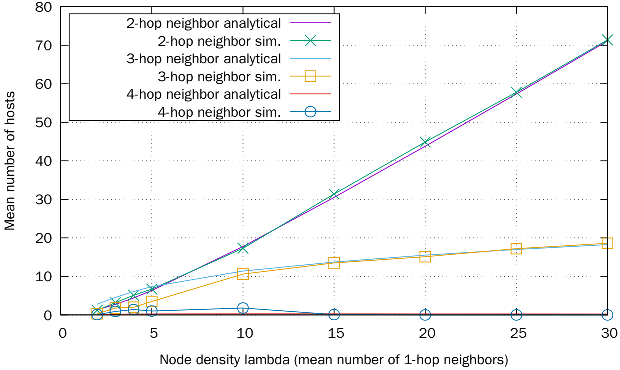
Number of 4-hop Neighbors



$$\begin{aligned}
&\mathbf{P}(\text{y(r3) is 4-hop}) = \\
&\mathbf{P}(\text{no node within A4(r3)})* \\
&\mathbf{P}(\text{at least one node in A5(r3)})* \\
&\mathbf{P}(\text{y(r3) is not 3-hop})* \\
&\int_{R}^{2R} \mathbf{P}(\text{w(r2) is 3-hop})r2\,dr2
\end{aligned} \tag{13}$$

$$\mathbf{E}[|N4|] = A_{ring}\lambda \frac{1}{A_{ring}} \int_0^{2\pi} \int_R^{2R} \mathbf{P}(\text{y(r3) is 4-hop})r3\,dr3\,d\theta \tag{14}$$

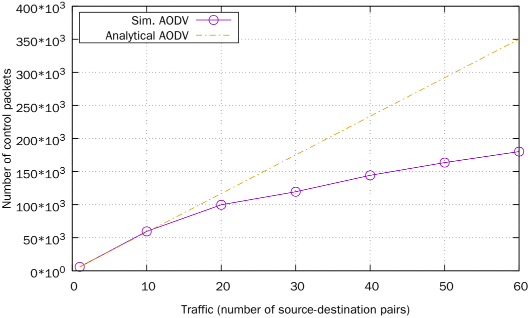
Model Validation: 4-hop Neighbors



- The analytical results and the simulation results match nicely
- There are very few 4-hop neighbors
- In simulations, no 4-hop neighbor is observed when the node density is very low ($\lambda = 2$) or high enough ($\lambda \geq 15$)

Control Overhead: AODV vs. OLSR

- The node density $\lambda = 15$
- N_{SD} is the number of the source-destination pairs

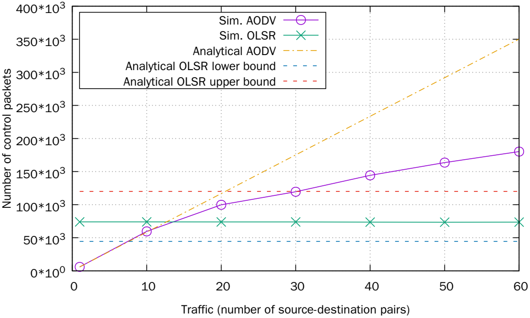


The difference increases along with the traffic intensity

- High traffic incurs high packet loss rate
- After `RREQ_RETRIES` attempts of failing to find a route for some applications, AODV signals them with Destination_Unreachable

Control Overhead: AODV vs. OLSR

- The node density $\lambda = 15$
- N_{SD} is the number of the source-destination pairs
- It is NP-hard to estimate the exact number of OLSR's control overhead, therefore we provide its lower and upper bounds
- OLSR's control overhead is independent to the traffic



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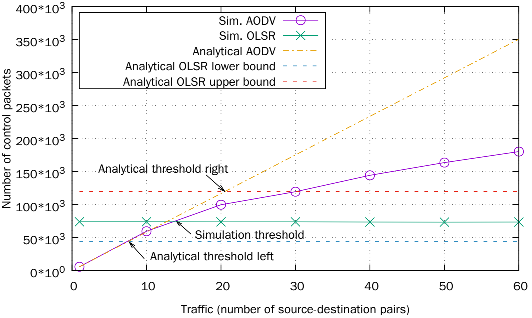


From the simulations:

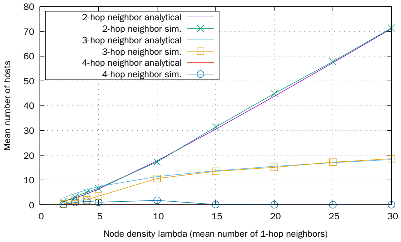
- AODV if $N_{SD} \leq 14$
- OLSR if $N_{SD} > 14$

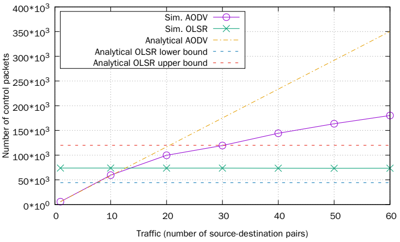
From the analytical model:

- AODV if $N_{SD} \leq 7$
- OLSR if $N_{SD} > 21$
- No change if $7 < N_{SD} \leq 21$

- The outcome (decision) of the analytical model is close to that of the simulations

Conclusions





- An analytical model is proposed for selecting the right MANET routing protocol, which provides the least control overhead
- The model is based on estimation of the number of *n*-hop neighbors, and each step is validated through simulations
- The outcome of the analytical model (when to use which routing algorithm) is close to that of the simulations

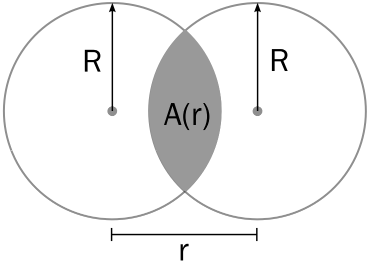
Thank You!

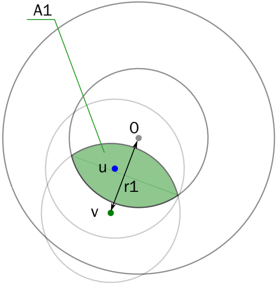
Questions?

Backup Slides

Area of the Intersection

Intersection A(r):





The area of A(r) solely depends on the distance r between the centers of the two circles:

$$A(r) = 2R^2 \arccos\left(\frac{r}{2R}\right) - r\sqrt{R^2 - \frac{r^2}{4}} \tag{15}$$

AODV Control Overhead

Assumption:

- No mobility $\rightarrow$ control overhead for route maintenance can be ignored

Notation:

- Ni: set of i-hop neighbors of the center node, where i = 1, 2, 3, ...

AODV route discovery procedure:

- To avoid flooding of the Route Request (RREQ) messages, the expending ring technique is used.
  - TTL[2] = 1, 3, 5, 7, ...
- If the destination is 1-hop away from the source, TTL = 1 is enough
  - Number of RREQ transmission: 1
- If the destination is 2-hop away, TTL = 1 and 3 are used
  - Number of RREQ transmission: $1 + 1 + |N1| + |N2|$
- If the destination is 3-hop away, same as above happens

[2] Time-To-Live

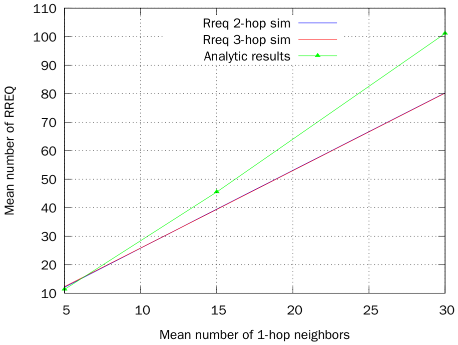
AODV Control Overhead

$$\mathbf{E}[|\text{RREQ}|] = \begin{cases} 1 & \text{if path length is 1} \\ 2 + \mathbf{E}[|N1|] + \mathbf{E}[|N2|] & \text{if path length is 2 or 3} \\ 3 + 2 \times \mathbf{E}[|N1|] & \\ \quad + 2 \times \mathbf{E}[|N2|] & \\ \quad + \mathbf{E}[|N3|] + \mathbf{E}[|N4|] & \text{if path length is 4 or 5} \end{cases} \tag{16}$$

A more general form:

$$\mathbf{E}[|\text{RREQ}|] = \begin{cases} 1 & L = 1 \\ 1 + \alpha + \sum_{k=1}^{\alpha} k(\mathbf{E}[|N_{L-2k+\beta}|] & \\ \qquad + \mathbf{E}[|N_{L-2k+\beta+1}|]) & L \in [2,7] \\ 1 + \alpha^* + \sum_{k=2}^{\alpha^*} k(\mathbf{E}[|N_{L^*-2k+\beta^*}|] & \\ \qquad + \mathbf{E}[|N_{L^*-2k+\beta^*+1}|]) & L \in [8,35] \\ \qquad + \mathbf{E}[|N_{rest}|] & \end{cases} \tag{17}$$

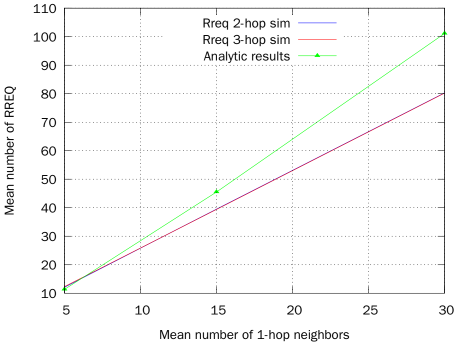
Model Validation: AODV Route Discovery



- Path length $L = 2$
- Number of Route Reply (RREP) messages equals to the path length
- No Route Error (RERR) messages

The gap between the analytical results and the simulation results increases along with the node density

Model Validation: AODV Route Discovery



- Path length $L = 2$
- Number of Route Reply (RREP) messages equals to the path length
- No Route Error (RERR) messages

The gap between the analytical results and the simulation results increases along with the node density

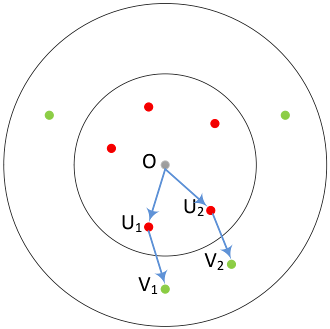
Reason for the difference:

When the node density increases, the possibility that a "theoretical" 2-hop neighbor becomes an "actual" 3-hop neighbor also increases.

As defined in Eq. (16),

$$\mathbf{E}[|RREQ|] = 1 + 1 + \mathbf{E}[|N1|] + \mathbf{E}[|N2|] \quad (18)$$

Example: A 2-hop Neighbor becomes a 3-hop Neighbor



- According to the euclidean distance, both V_1 and V_2 are 2-hop neighbors of node 0.
- V_1 is not within U_2's coverage, and V_2 is not within U_1's coverage.

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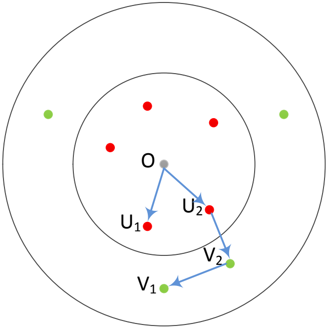

- According to the euclidean distance, both V_1 and V_2 are 2-hop neighbors of node 0.
- V_1 is not within U_2's coverage, and V_2 is not within U_1's coverage.
- In 802.11 contention based MAC, V_1 becomes a 3-hop neighbor, if the random backoff (BO) fulfills the following relation: $\mathrm{BO}(U_1) > \mathrm{BO}(U_2) + \mathrm{BO}(V_2)$