Integrating Stability Estimation into Quality of Service Routing in Mobile Ad-hoc Networks

Weiying Zhu, Min Song, and Stephan Olariu
Old Dominion University, Norfolk, Virginia, U.S.A

Speaker: Weiying Zhu
wzhu@odu.edu

Outline

- Introduction
- Estimation of the Relative Link and Path Stability
- Ticket Based Probing with Stability Estimation
- Simulation Study
- Concluding Remarks and Future Work

QoS Routing in MANET

- Strict QoS that is pursued in traditional wired networks is too hard to be achieved in MANET.
  - This is due to the dynamic nature of network topology and imprecise network state information.
  - The established path for a connection request may break before the end of data transmission.
- Soft QoS provisioning is accepted in MANET.
  - The negotiated QoS parameters are allowed to be violated for short, transient time periods.
  - When the established path is broken, either a new connection request is initiated or the path is rerouted.
  - Frequent path breakages may result in large delay, transmission failure, increased routing message overhead, and wastage of network resources.

Mitigate the Effect of Path Breakage

- Predict future paths before existing ones break.
  - The timely path rediscovery highly relies on the accurate estimation on lifetime of links and paths, which is very hard due to the various movement models of mobile nodes.
  - It does not reduce path breakage so that some problems such as transmission failure and big routing message overhead still exist.

- In cluster-based routing, construct paths along virtual backbone formed by cluster headers with smaller absolute speeds.
  - The stability of a path is determined by the relative speeds between nodes forming the path instead of their absolute speeds.
  - The effect of path breakage due to mobility is ignored during path selection.
  - Geographic locations need to be obtained via GPS or similar devices.

Our Solution

- Integrate stability estimation into path discovery and path selection to efficiently reduce path breakage during data transmission even if geographic location information is not available.
  - Models and metrics are proposed to estimate the relative link and path stabilities.
  - Relative link stability and relative path stability are used to discover the paths with high stability.
  - When multiple feasible paths are discovered, the one with the highest relative stability is selected.

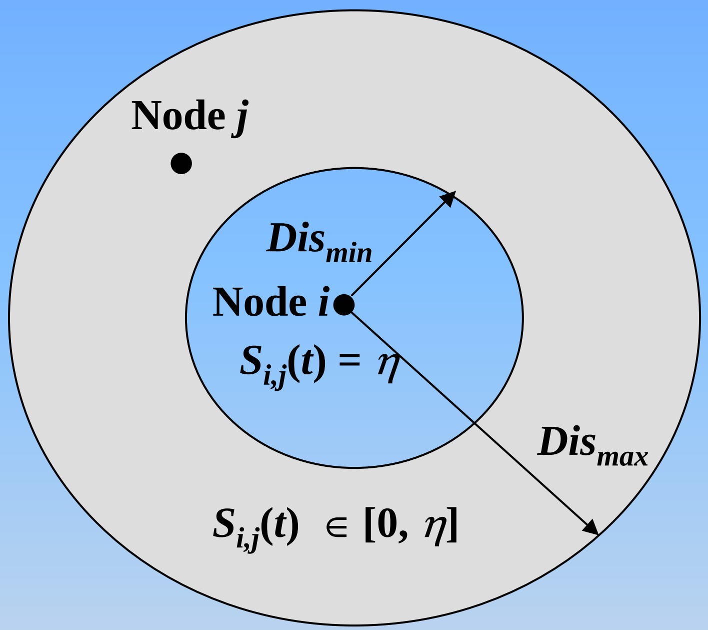
- Extend a well-known distributed MANET QoS routing scheme, ticket-based probing (TBP), to demonstrate our solution.

Distance between two neighbor nodes

- The distance between neighbor nodes *i* and *j*, $Dis_{i,j}(t)$, needs to be calculated and maintained.
  - For GPS-enabled nodes, $Dis_{i,j}(t)$ can be easily calculated.
  - Based on the radio propagation model, for nodes without GPS, $Dis_{i,j}(t)$ can be estimated using the signal strength of beacon message in neighboring discovery.
  - Assuming that *T* is the period with which beacon messages are broadcast, at time *t*, node *i* updates both $Dis_{i,j}(t - T)$ and $Dis_{i,j}(t)$ for every neighbor node.

Estimate Link Stability Rate $S_{i,j}(t)$

- Rule 1: If $Dis_{i,j}(t) \le Dis_{min}$, then nodes i and j are very close and $L_{i,j}$ is considered to be sufficiently stable so that $S_{i,j}(t) = \eta$;
- Rule 2: If node j is a new neighbor of node i, that is, at time $t - T$, node j is not the neighbor of node i, then $S_{i,j}(t) = 0$;
- Rule 3: If $Dis_{i,j}(t) \le Dis_{i,j}(t - T)$, then nodes i and j are approaching each other and $L_{i,j}$ is considered to be sufficiently stable so that $S_{i,j}(t) = \eta$;



$L_{i,j}$: The link between nodes i and j;

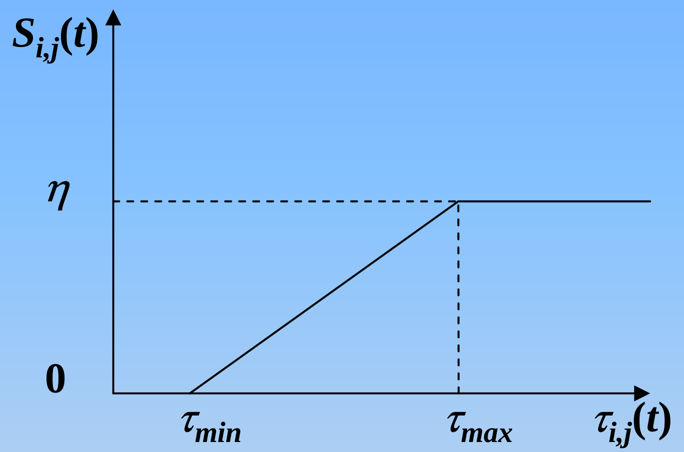
Dis_{max}: Transmission range of nodes;

Dis_{min}: Minimum distance;

η: The maximal stability rate, and $0 \le \eta < 1$.

Estimate Link Stability Rate $S_{i,j}(t)$ (Cont.)

- Rule 4: Let $\tau_{i,j}(t)$ represent the expected duration, at time t, that the link $L_{i,j}$ remains unbroken. And
$$\tau_{i,j}(t) = \frac{Dis_{max} - Dis_{i,j}(t)}{Dis_{i,j}(t) - Dis_{i,j}(t-T)};$$
- Rule 5: If $\tau_{i,j}(t) \geqslant \tau_{max}$, then the link is considered to be sufficiently stable so that $S_{i,j}(t) = \eta$;
- Rule 6: If $\tau_{i,j}(t) \leqslant \tau_{min}$, then the link is considered to break soon so that $S_{i,j}(t) = 0$;
- Rule 7: $S_{i,j}(t) = \frac{\tau_{i,j}(t) - \tau_{min}}{\tau_{max} - \tau_{min}} \times \eta$.



τ_{min} and τ_{max}: Two positive threshold values defined for $\tau_{i,j}(t)$.

Estimate Path Stability Rate ($S_P(t)$)

- The probability that a path is non-broken equals to the product of the probabilities that its links are non-broken, i.e.

$$\Pr\{P \text{ is non-broken}\} = \Pr\{L_{s,r_1} \text{ is non-broken}\} \times \prod_{k=1}^{n-1} \Pr\{L_{r_k,r_{k+1}} \text{ is non-broken}\} \times \Pr\{L_{r_n,d} \text{ is non-broken}\},$$

where $P = s \rightarrow r_1 \rightarrow r_2 \rightarrow \ldots \rightarrow r_n \rightarrow d$.

- Hence, the path stability rate of P at time t, $S_P(t)$, is defined as follows:

$$S_p(t) = S_{s,r_1}(t) \times \prod_{k=1}^{n-1} S_{r_k,r_{k+1}}(t) \times S_{r_n,d}(t).$$

Ticket Based Probing (TBP)

- TBP is a multi-path distributed QoS routing scheme.
  - Every node keeps up-to-date link delay and link cost for each of its neighbor nodes, and the imprecise end-to-end state information for every node in the networks.
  - For a connection request, the source node generates a certain number of yellow tickets to detect paths with low delay and a certain number of green tickets to detect paths with low cost.
  - At a source or intermediate node, tickets are distributed among its neighbor nodes.
  - If a neighbor node is allocated at least one ticket, a probe carrying all the tickets allocated to this neighbor node is sent to this neighbor node.
  - Finally, each of the probes that successfully arrive at the destination node detects a feasible path. Among them, the path with the lowest cost is selected.

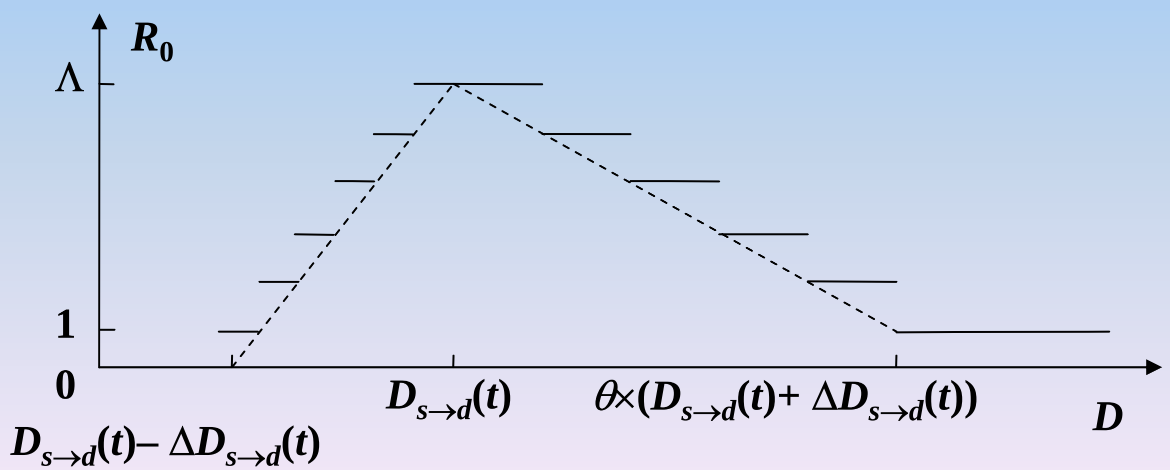
Extend TBP to Integrate Stability Estimation

- Modify TBP into Ticket Based Probing with Stability Estimation (TBP-SE)
  - Introduce new QoS state variables;
  - Generate and forward a new group of tickets, red tickets, which should be sent along paths with relatively high stability;
  - At the destination node, among all feasible paths, select the one with the highest path stability rate.

- At node *i*, two new groups of state variables are introduced to specify stability:
  - $S_{i,j}(t)\ \forall j \in N_i$: Record the up-to-date link stability rates for outgoing links.
  - $S_{i\rightarrow d}(t)\ \forall d \in V$: Record the estimated largest end-to-end path stability rate from node *i* to node *d*.

Determine the Number of Red Tickets (R_0)

- When delay requirement, *D*, is sufficiently large, one red ticket suffices to detect a feasible path with high stability.
- When *D* is larger than the estimated end-to-end delay, $D_{s\to d}(t)$, as *D* becomes smaller, R_0 is increased to increase the probability that a feasible path with high stability is detected.
- For a stringent *D* which is smaller than $D_{s\to d}(t)$, the main objective is to detect a feasible path instead of optimizing path stability. As *D* becomes smaller, R_0 decreases in order to reduce the routing overhead.
- When *D* is too stringent to be satisfied, no ticket is issued.



Distribute Red Tickets

- Select the candidate neighbor nodes that are eligible for receiving tickets.
  - A probe records the accumulated path delay, *delay*(P^{tr}), accumulated path stability rate, *stab*(P^{tr}), and the set of traversed nodes, V^{tr}, while it travels.
  - Criteria 1: This neighbor node has NOT been traversed by the probe previously.
  - Criteria 2: The minimum path delay from the source node to the destination node via this neighbor node MUST be expected to be less than *D*.

- Distribute a certain number (*X*) of red tickets among the candidate nodes, the set of which at node *i* is denoted as R_i. $\forall j \in R_i$,
  - $\overline{X}_j = \dfrac{S_{i,j}(t) \times S_{j \to d}(t)}{\sum_{j' \in R_i} (S_{i,j'}(t) \times S_{j' \to d}(t))} \times X$, $X_j = \lceil \overline{X}_j \rceil$ for larger $\overline{X}_j$, and $X_j = \lfloor \overline{X}_j \rfloor$ for smaller $\overline{X}_j$.

- Send a new probe to node *j* if $X_j > 0$ and $j \in R_i$.
  - This probe carries X_j red tickets and other tickets allocated to node *j* if any.
  - This probe also carries the updated *delay*(P^{tr}), *stab*(P^{tr}), and V^{tr}.

Select Path at the Destination Node

- When a probe arrives at the destination node, a path that satisfies the delay-constraint is detected.
- It is far more important than other optimization objectives for a path to have high stability.
  - Among all the feasible paths, the one with the highest path stability rate is selected as the primary path.
- There is no need to generate and forward green tickets for detecting low cost paths.

Mobility Model

- The ***random waypoint*** model is adopted to simulate the movement of mobile nodes.
  - Field: a two-dimension $L \times W$ rectangular area.
  - Moving direction is chosen uniformly within $[0, 2\pi)$.
  - Moving speed is chosen uniformly within $(0, 2 \times V_{mean}]$.
  - Moving duration is chosen uniformly within $(0, 2 \times T_{mean}^{mov}]$.
  - Pause duration is chosen uniformly within $(0, 2 \times T_{mean}^{pause}]$.
  - Mobility rate is defined as the ratio of T_{mean}^{mov} to T_{mean}^{pause}.
  - For every connection request, the data transmission duration is chosen uniformly within $[T_{min}^{trans}, T_{max}^{trans}]$.

Performance Metrics

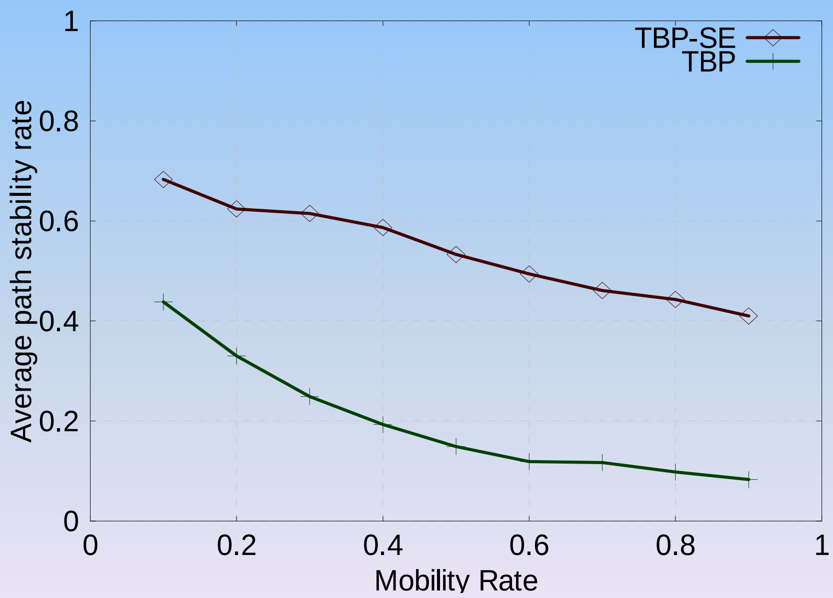
- $$\text{Average path stability rate} = \frac{\text{total path stability rate of all seleted paths}}{\text{number of accepted connection requests}}$$
  - It indicates how efficiently paths with high stability rate are detected.
- $$\text{Percentage of non-broken paths } (t) = \frac{\text{number of selected paths that exist for at least time } t}{\text{number of selected paths}}$$
  - The increase of the percentage of non-broken path reflects the decrease of the path breakage speed.
- $$\text{Success ratio} = \frac{\text{number of connections whose data transmissions are completed}}{\text{number of connection requests}}$$
  - Only if the selected path remains non-broken until data transmission is completed, the connection request is going to succeed.
- $$\text{Average message overhead} = \frac{\text{number of messages sent}}{\text{number of connection requests}}$$
  - When a node sends a probe to over a link, one message is counted.

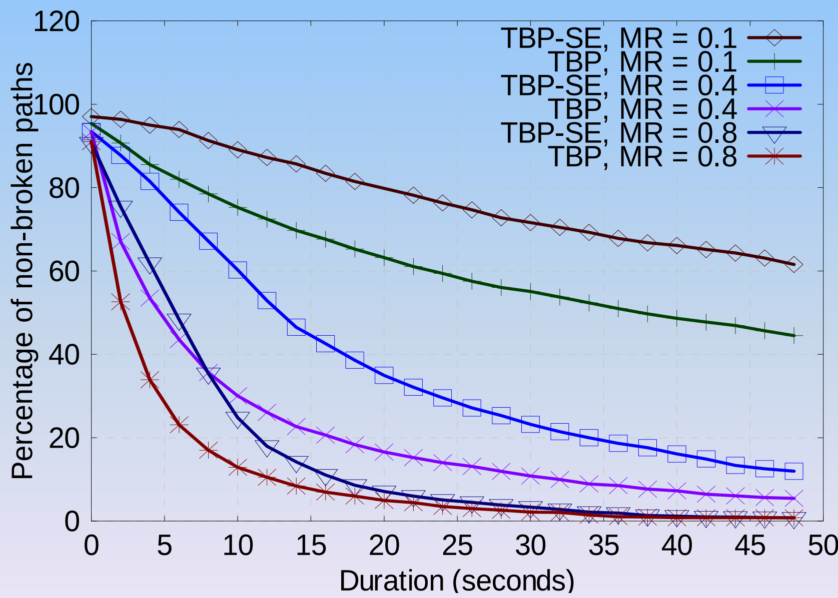
Simulation Parameters

System parameter	Value	System parameter	Value
L	20 meters	θ	1.7
W	20 meters	V_{mean}	0.3 meter/second
Number of mobile nodes	50	T_{mean}^{mov}	50 seconds
Dis_{max} (Transmission range)	5 meters	Average link delay	50 milliseconds
Dis_{min}	0.3 meter	Imprecise rate of link delay	0.1
τ_{min}	10 seconds	Average link cost	100
τ_{max}	500 seconds	Imprecise rate of link cost	0.1
η	0.9	D_{min}	30 milliseconds
Φ (Maximum number of yellow tickets)	5	D_{max}	1000 milliseconds
Ω (Maximum number of green tickets)	4	T_{min}^{trans}	0.5 second
Λ	4	T_{max}^{trans}	10 seconds

Simulation Results

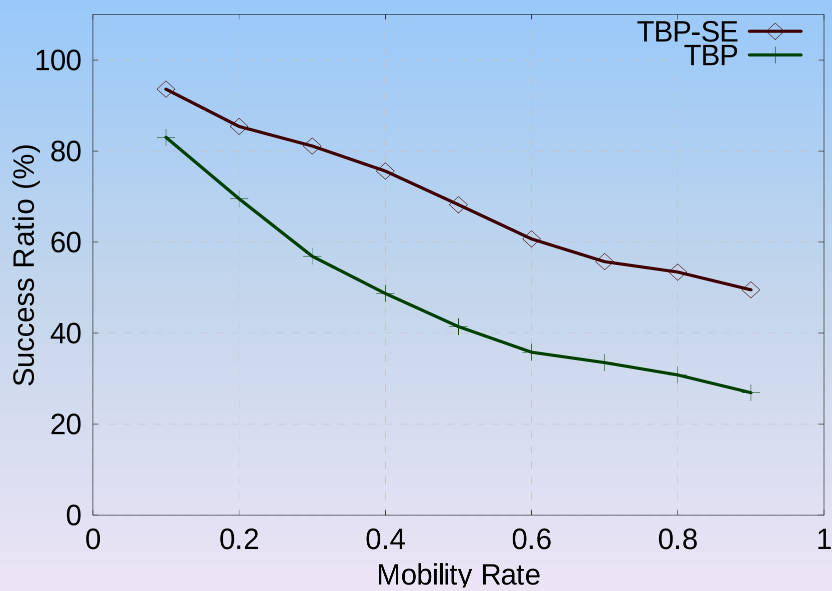
- As the mobility rate increases, the average path stability rates of both TBP and TBP-SE decrease.
- TBP-SE can always detect paths with much higher stability rate than TBP.
- The percentage of non-broken paths of TBP drops much faster than that of TBP-SE as *t* increases.
- TBP-SE detects paths remaining non-broken for longer duration than TBP.



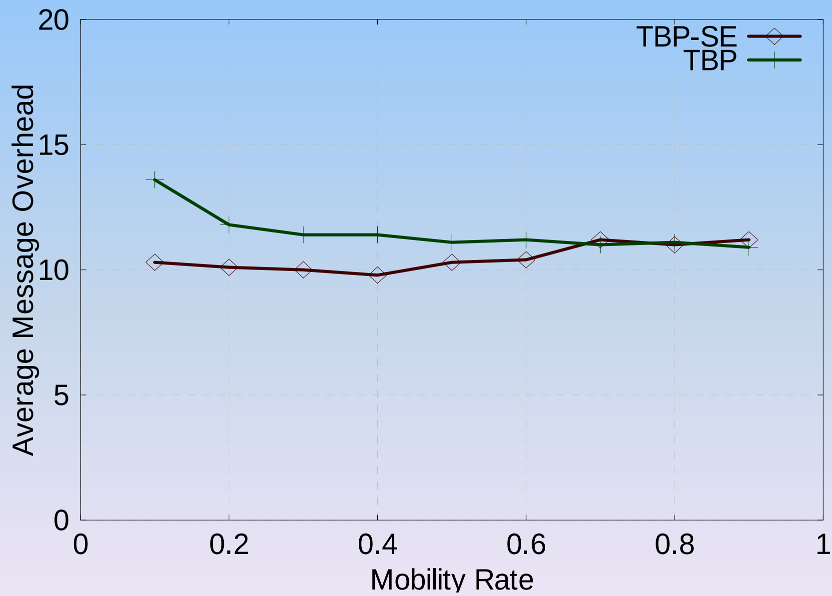


Simulation Results (Cont.)

- Compared with TBP, TBP-SE significantly increases the probability that data transmission is completed before the selected path breaks.



- In terms of the QoS routing message overhead per connection request, TBP-SE and TBP are similar.
- TBP-SE reduces the number of connection requests for re-transmission and/or re-routing.



Conclusions

- Models are proposed to estimate the relative stability of links and paths.

- Using delay-constrained QoS routing problem as an example, TBP-SE is proposed.
  - Extensive simulations indicate that TBP-SE efficiently reduce the path breakage before the end of data transmission.
  - The average QoS message overhead per connection request of TBP-SE is kept at the same level as TBP.

Future Work

- When other optimization objectives need to be considered, such as low link utilization, more groups of colored tickets can be generated.
  - At the destination node, based on a weighted combination of all objectives, the primary path is selected among all the feasible paths.
- The estimation mode of the expected non-broken duration of a link can be enhanced.
- Our solution can be used to integrate the stability estimation into other QoS routing schemes.

Questions?

Thank you!