# Quality of Service Routing in Ad Hoc Networks

G.V.S. Raju, G. Hernandez, Q. Zou.
Division of Engineering.
The University of Texas at San Antonio.
San Antonio, TX 78249-0665
Email: raju@utsa.edu

***Abstract*- Current generation routing protocols for ad hoc networks typically use shortest-path routing. Examples include on-demand routing protocols such as DSR and AODV. All these protocols can support only the best-effort data traffic, but the quality of service (QoS) requirements, such as delay, packet loss and bandwidth requirements are not supported. In the wireline networks such as ATM, QoS routing has been studied extensively. Due to dynamic nature of ad hoc networks owing to mobility and varying radio link conditions, the available state of information is never precise, and consequently, we cannot directly apply the traditional wireline QoS routing algorithms. Soft QoS without hard guarantees is explored here.**

**Recently, work in QoS routing in ad hoc networks is reported in [1], where delay and bandwidth constrained QoS routings were studied separately. The uncertainty was handled using a deterministic model. The algorithms developed in this paper accommodate imprecise state information. Fuzzy logic is a well recognized technique for modeling imprecision. A rule based fuzzy logic model is used to describe imprecise state information. Delay constraints are considered here in finding feasible routes (paths). Among feasible paths, optimal path (least cost path) is found using hop count as a performance measure. In case of re-routing, sub-optimal paths are found using the same performance measure.**

## I. NETWORK MODEL AND ASSUMPTIONS

We assume the existence of a neighbor discovering protocol. Each node periodically transmits a packet identifying itself, so that any node $i$ knows the set $V_i$ of its neighbors . Each message is transmitted by a local broadcast. We also assume the existence of a MAC protocol, which resolves the media contention, supports resource reservation, and ensures that only that the intended receiver in the local broadcast range gets the transmitted packet [2]. The links between a stationary or slowly moving nodes are likely to exist continuously. The links between the fast moving nodes are likely to exist only for a short period of time. The former links are called stationary and the later ones are called transient. A routing path should use stationary links whenever possible and avoid transient links. A node is assumed to keep up-to-date local state information about all outgoing links [1].

Local link information consists of link delay, unused link bandwidth, and link cost in terms of hop count or path utilization factor. For illustration, let us consider the network shown in figure 1. Every node $i$ also maintains end-to-end state information of every possible destination. The end-to-end state information consists of end-to-end-delay of lowest delay path from node to destination $D_{ir}$, end –to –end bandwidth of the largest bandwidth path $B_{ir}$, and end-to-end cost of the least cost path $C_{ir}$. For ad hoc networks, the above

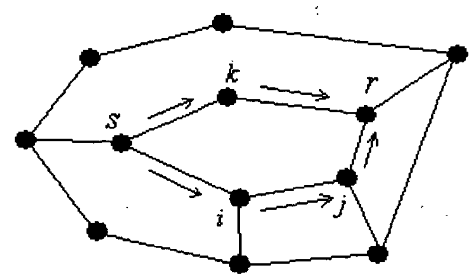


Fig.1 Two probes from source $s$ to destination $r$.

information is not precise. Guerin and Orda [3] expressed the imprecision of $D_{ir}$ , $B_{in}$, and $C_{ir}$ by a probability distribution function. This model is not suitable for an ad hoc network because nodes go in and out of range frequently and a meaningful probability distribution is hard to obtain. In Chen and Nahrstedt [1], the imprecision is modeled by assuming that the delay will vary between $D_{ir}$ - $\Delta D_{ir}$ and $D_{ir}$ + $\Delta D_{ir}$ and bandwidth will be between $B_{ir}$ - $\Delta B_{ir}$ and $B_{ir}$ + $\Delta B_{ir}$ where $\Delta D_{ir}$ and $\Delta B_{ir}$ are delay and bandwidth variations, respectively. The $\Delta$ terms model uncertainty. At each node, five parameters, $D_{ir}$ , $B_{ir}$ , $C_{ir}$ , $\Delta D_{ir}$ and $\Delta B_{ir}$ are maintained and updated periodically using one of the existing routing protocols.

In our QoS routing approach, no flooding is used to discover path because, in flooding, routing messages are sent to the entire network. Instead, search is limited to a small number of paths from source $s$ to destination $r$. Since there are many paths from $s$ to $r$, an intelligent hop-by-hop path selection is made to guide the search along the best candidate paths.

## II. PROBLEM STATEMENT

Given a source node $s$, a destination node $r$, an end-to-end delay requirement $D_r$, the problem is to find a feasible path from $s$ to $r$ such that the path delay $\leq D_r$ . When there are multiple feasible paths, the path with the least cost in terms of hop count or path utilization factor is selected. In real-time applications, such as voice and video, delay plays a critical role, whereas in data applications packet loss, as a consequence of the lack of bandwidth, is very important. In [1,3,5,6,7], for the QoS routing, the delay constrained routing

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and the Bandwidth-constrained routing are studied separately. In [1] a connection request arrives at the source node with certain delay $D_r$ and bandwidth $B_r$ requirements.

To limit the search, the source node estimates how many feasible search paths are to be allowed towards destination, depending on (i) $D_{sr}$ and the $\Delta D_{sr}$ in the case of delay-constrained search and (ii) $B_{sr}$ and $\Delta B_{sr}$ in the case of bandwidth constrained search. Note that $D_{sr} + \Delta D_{sr} \leq D_r$ and $B_{sr} - \Delta B_{sr} \geq B_r$.

Among the feasible paths, the least cost path is chosen as the optimal one. We propose a distributed QoS routing scheme that selects a network path with sufficient resources to satisfy a certain delay requirement in a dynamic multihop mobile environment.

The proposed approach will accommodate imprecise state information. Fuzzy logic is a well recognized technique for modeling imprecision [4,8]. A rule based fuzzy logic control model is developed to generate $M$, the maximum number of probes (queries) that are allowed to search for feasible paths from source to destination. In developing this model, the following factors are considered: (i) too small value of $M$ may result in failure to find a path and (ii) too large the value of $M$ may increase routing overhead. Applications that require unusual QoS requirements such as small delay and high bandwidth, may be allowed to have large $M$ for more searching of feasible paths. The level of uncertainty ($\Delta D$) also increases the need for a larger $M$.

When a connection request arrives at a source node with certain delay requirement $D_r$, the source node estimates form the rule based fuzzy model, how many feasible search paths M are to be allowed towards destination depending on four parameters ($D_r$, $D_{sr}$, $\Delta D_{sr}$,) where $\Delta D_{sr}$ stands for the end-to-end delay variation of the path.

When a probe reaches destination, a feasible path is found. If multiple queries reach destination, the least cost one is primary path and others are secondary paths, which can be used when rerouting is necessary or desired. A confirmation message is sent back to the source and a time out mechanism is used to prevent indefinite waiting.

If an intermediate node detects a broken path, it sends an appropriate error message back to the source, which in turn reroutes the connection to the secondary least cost path.

## III. Role of Fuzzy Decision System

We propose a Fuzzy logic-based decision making system (see figure 2) to allow the probes to search for the best path that will lead to a high QoS level for the connection. As the source node $s$ receives a request with certain delay requirement, it checks all available paths and analyzes the state of their links based on their Distance Vector tables.

As a fuzzy system, the decision is based on inference rules for generating the number of probes depending on the values

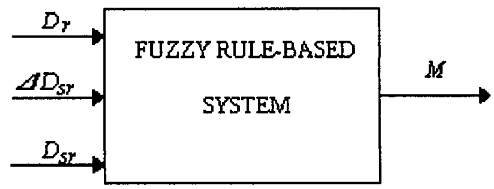


Fig 2. Role of the fuzzy system.

for the inputs. For every inference rule the value for Delay requirement, Delay, and Delay variation (as part of fuzzy sets,) are evaluated. Rules have the If-Then structure, linked by AND logical operators, to provide the system with enough tools to make inferences and calculate a crisp final output.

Based on the fuzzy system, the source node generates a number of probes to search for more feasible paths. The decision to generate more probes in order to find a feasible path is made based on the Fuzzy input variables (state information): Delay $D_{sr}$, Delay variation $\Delta D_{sr}$ and Delay requirement $D_r$. The output for the system is the initial number of Probes $M$ to be sent for finding feasible paths. Probes are then sent from source toward destination searching for a low-delay, low-cost path that satisfies the delay requirement for the connection.

As described in [1], all intermediate nodes, based on the link state for every instance of time, should decide either to split the probe or not, and decide which neighbor nodes the probe(s) should be forwarded to. The difference between our proposed model and the Chen and Nahrtstedt algorithm is the way to deal with the uncertainty of the changing conditions for the value of the delay, as well as its historical trend due to the nature of ad hoc networks. If in one specific path the delay is more likely to keep low and the requirement for the connection is high, then more probes are generated to keep looking for that path until the destination is reached. On the contrary, if the delay is low and the historical trend shows the inclination to get too high on time, and also the Delay requirement is high for that connection, then the required QoS for that specific path is less likely to be accomplished. Fewer amounts of probes are generated and the probability of further searching for this path is low. This connection is more likely to be rejected and the alternative paths will be considered depending on their delay, delay variation and cost values.

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