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TEMPORAL ROUTING IN DELAY TOLERANT NETWORKS

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TEMPORAL ROUTING IN DELAY TOLERANT NETWORKS

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ABSTRACT

In conventional network environments, routing implies a stable world in which the vision of a next hop is consistent with the vision a forwarding node, so that a packet can progress, for example, in a greedy fashion that reduces a remaining cost at each hop, to a destination. However, in the world of mobile delay tolerant networking (DTN), nodes can move in any direction, nodes may forward packets when they meet a peer, and may move in between such actions. Thus, the relative position of nodes can change between meeting such that it can become difficult to compute a physical path based on a position of all nodes. Techniques presented herein propose a foundational "routing to the future" model for mobile DTN nodes that may enable predictable rendezvous among such nodes. During operation, a router can, for example, compute a route along rendezvous points while optimizing for the total latency, energy, and chances of delivery based on the probability of the rendezvous to effectively occur.

DETAILED DESCRIPTION

For mobile delay tolerant networking (DTN), nodes can move in any direction. In such DTN environments, nodes may forward packets when they meet and then continue to move in between such meetings such that the relative position of nodes can vastly change between meetings. Thus, it becomes difficult in such environments to compute a physical path based on the position of all nodes at an initial time (e.g., T_0) and expect that the path will remain consistent for the duration of a DTN transmission.

Presented herein are techniques that provide a foundational "routing to the future" model for mobile DTN nodes that may enable predictable rendezvous among network nodes in order to facilitate packet routing in DTN environments. Broadly, techniques herein provide for computing a path in time based on the current visibility of rendezvous points in the future. The map of the future can evolve with addition of shuttles and cancelling of rendezvous, and new maps can be gossiped or broadcast between the mobile DTN nodes. Additionally, the maps on the futures can be reordered with main re-computations and deltas such that rules for rerouting can be provided using a newer map of the future.

Such an operating environment involving mobile DTN nodes can be distinguished from a conventional time-based routing environment, as is often utilized in Low-Earth Orbit (LEO) satellite communications in which routes are often enabled during periodic and predictable rendezvous. For mobile DTN nodes, rendezvous are not expected to be periodic, and routes are not expected to be enabled/disabled. In contrast, the path of an LEO satellite is typically considered to be stable during the time of forwarding of a packet, which is analogous to a traditional forwarding based on time-based enabled routes.

However, for techniques of this proposal, a path in the future is computed because packets can be physically transported, at least some distance, by the mobile nodes themselves, and forwarding is slower than the route changes (e.g., Nodes A, B, and C may be aligned at one point of time and Node A may decide to pass the packet to Node B when they meet, so that later Node B can pass the packet to Node C. But if Node B is going to the left and Node C to the right, Nodes B and C will not meet and the can routing fails)

Thus, in accordance with the techniques of this proposal, mobile DTN nodes may utilize time, as opposed to space, as the consistent basis on which routes can be computed. To facilitate operations is proposed herein, it is expected that a controller can foresee the times in some future when any two nodes will meet with some statistical chance that it will happen and build a map of the future with that aggregated information. In the context of the techniques proposed herein, a "meeting" between nodes can be characterized as a physical nearby presence between nodes, for example, two vehicles within Wi-Fi range of each other, low-earth orbit (LEO) satellites within a temporary line of site of each other for laser communication, or any other physical presence through which communications can be facilitated between nodes.

The map of the future is considered to have an event horizon as it describes meetings in a visible future, up to a certain date. Only paths that complete within the event horizon date of a map can be computed with the map. A node may need to wait for a newer map when the current map that it has in memory becomes too old or does not contain a feasible path within the event horizon date of the map.

For example, consider a scenario as illustrated in Figure 1, below, in which, based on current knowledge, a controller can compute a first map (Version 1 (V1.0)) at a time T1 that it then revisits and redistributes periodically to all DTN nodes for an environment (e.g., using gossiping or a broadcast method, such as may be facilitated via Multicast Protocol for Low-Power and Lossy Networks (MPL) (as defined in Internet Engineering Task Force (IETF) Request For Comments (RFC) 7731) communications, or the like).

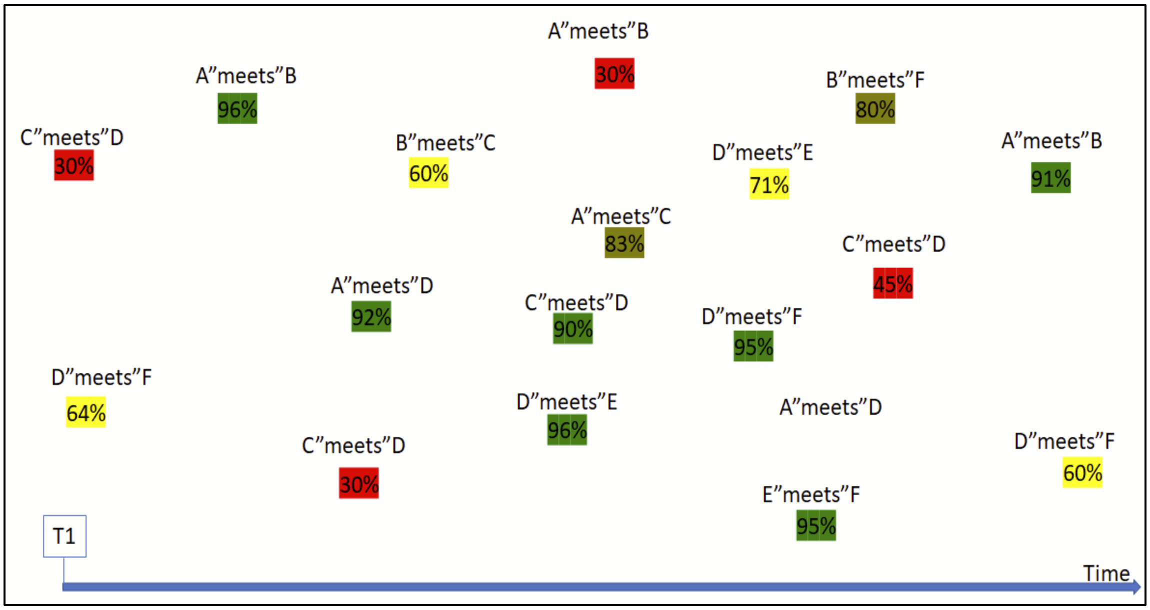

Figure 1: Map of the Future V1.0 at Time T1

With reference to the example map of the future of Figure 1, consider an example scenario in which a Node A needs to pass a packet to a Node F. As shown in Figure 2, below, Node A can compute the sequence of Nodes A, B, C, D, and F based on the fact that, in the future, Node A will meet Node B, then Node B will meet Node C, Node C will meet Node D and Node D will meet Node F, in that order.

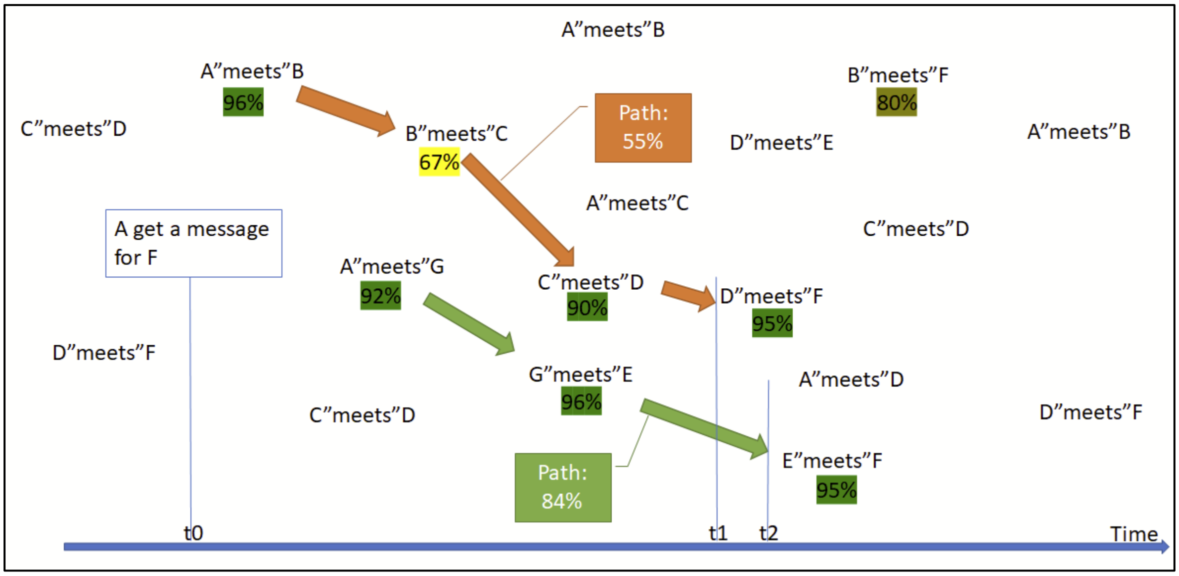

Figure 2: Map V1.0 Example Scenario Involving Node A -> Node F Path Computation

Different potential routing solutions for the computation can be evaluated based on:

- The total duration of the transfer from Node A to Node F. [In the example shown in Figure 2, above, the orange path yields a delivery sooner than the green path.];
- The statistical chances that all rendezvous will occur along the path. [In the example of Figure 2, the probability of delivery, which depends on the probability of each meeting happening, is better for the green path. If the policy is higher reliability, then the green path can be chosen, or 2 copies may be sent, one on each path.]; and/or
- Potentially, some cost, such as memory and energy if the devices are battery operated, or some other cost-related consideration.

Based on policy, the sender, Node A in this example, can select one sequence and mark the packet with that sequence (e.g., using source routing). When Node A meets Node B, Node A passes the packet to B, which reads the marking and stores the packet to give it to Node C when Nodes B and C meet.

The message is tagged with the sequence of the map of the future that was used to compute the sequence and the policy that is applied to select the best path. A node on the way may recompute a given path in two cases: 1) If a meeting does not happen, in which the node that has the message can compute a new path the same way as described above; or 2) if the node that receives the message has a newer map of the future that yields a better result.

As time passes, the controller may emit updates of the last/previous map (e.g., V1.1, V1.2, etc.) that are deltas of the last/previous map. A delta may indicate a meeting that is cancelled, in which case a node that forwards a packet that requires the cancelled meeting in the future needs to reroute the packet to use rendezvous points that are still in the map. The controller can also send a whole new map periodically, in order to resynchronize the nodes of the whole future meeting in a new future event horizon.

In some instances, the controller may also schedule shuttles that will circulate between mobile nodes in order to create additional forwarding opportunities. For example, as shown in Figure 3, below, consider that the controller dispatches a shuttle at time = T2, which occurs sometime after issuing map V1.0.

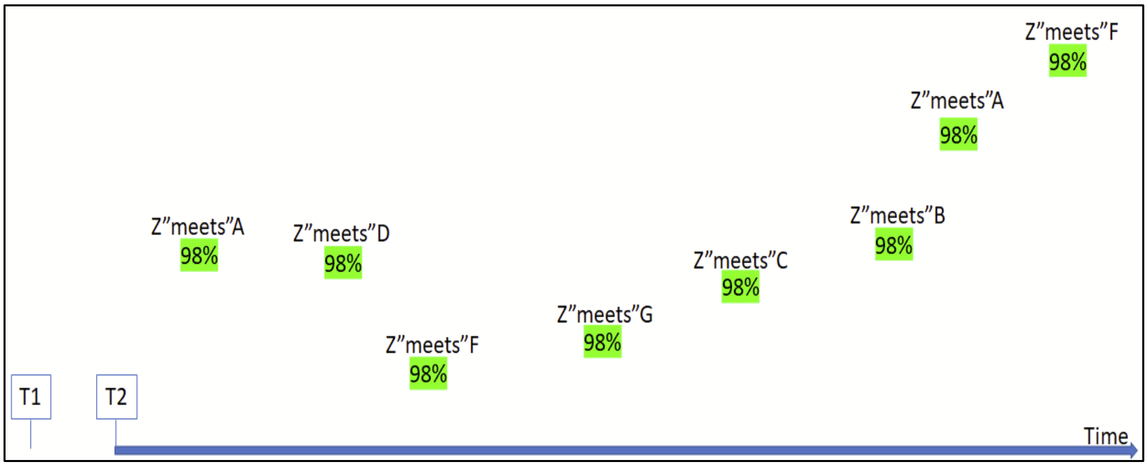

Figure 3: Computing a Shuttle

For the present example, upon receiving that update, a node the has the V1.0 map can apply the changes based on the introduction of the shuttle, resulting in map v1.1, as shown below in Figure 4.

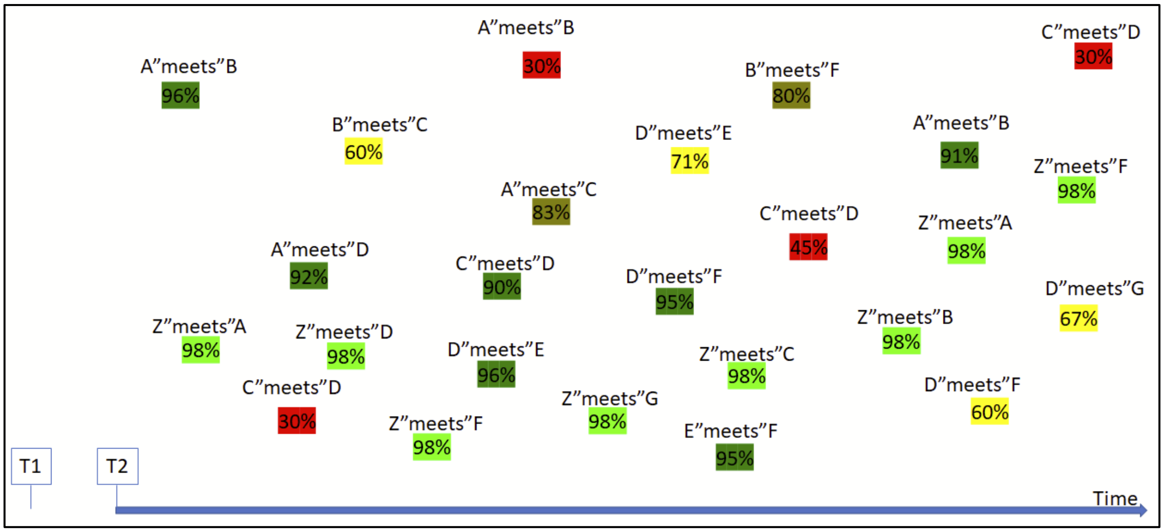

Figure 4: Map of the Future V1.1 at Time T2

A node that uses an updated map needs to indicate the level of the map (e.g., v1.1) that has had a continuous series of updates since V1.0. (e.g., if the node later receives V1.3 but not V1.2, it will indicate V1.1 in the routes it computes).

Using the shuttle, Node A now has a faster and more reliable path in the future to reach Node F, as illustrated in Figure 5, below.

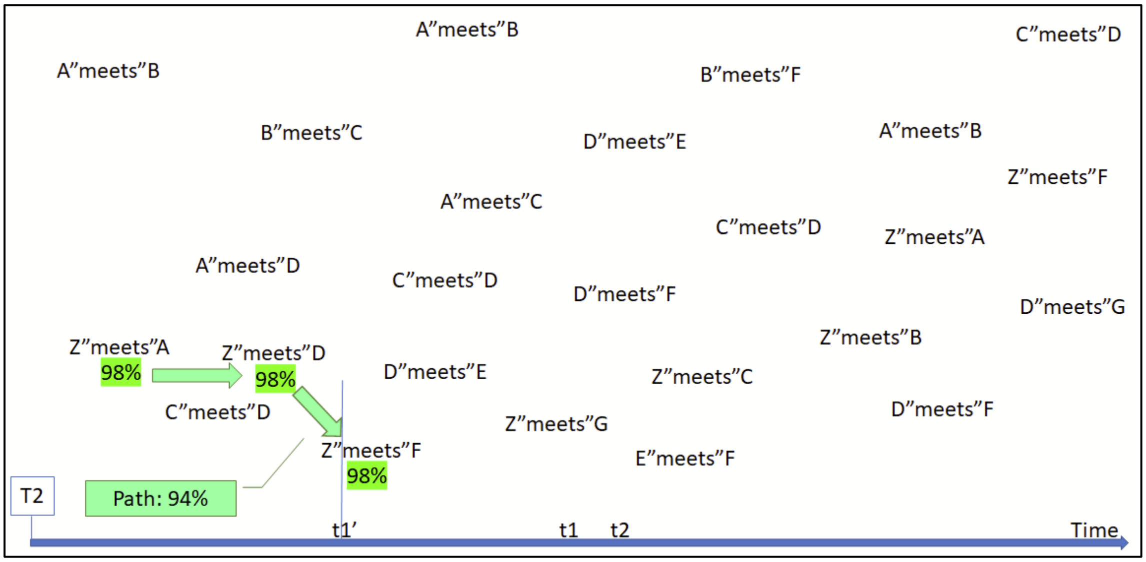

Figure 5: Updated Path Computation Based on Map of the Future V1.1

In some instances, a message may be tagged with a lifetime in which case the message can be dropped upon time out. In some instances, messages may also be tagged with a sequence to eliminate duplicate messages.

In accordance with techniques of this proposal, when any nodes meet, they can synch or share the map of the future. Thus, new maps that are injected by the controller can percolate in throughout a network and nodes can compute new routes further down in the future.

The duration of the map that the controller produces must foresee enough in the future to allow the gossiping and the route computation. If a node has a map that is too old and does not go far enough in the future, it may not be able to compute a path beyond that event horizon, so it needs to wait for a newer map that allows it.

Consider an example scenario in which techniques of this proposal may be implemented in which rendezvous points in the future are organized by a fleet management system. For example, a fleet management may tell a truck to pass via street 100 between T1 and T2 as this other truck is scheduled to be loading, creating an organized rendezvous point for such an environment. A key aspect of this proposal is to be able to visualize those rendezvous points in the time domain, similar to how routers are viewed in the normal spatial domain and as routes are computed between them.

Thus, the cost in the time domain is the time between rendezvous points. In accordance with techniques of this proposal, the shortest paths involving such rendezvous metrics can be calculated in order to facilitate packet transmissions. Additionally, such techniques can be enhanced such that the route computation can include a statistical metric of the chances that the rendezvous effectively occur (which can be distinguished from routers existing in the spatial domain that are effectively present with a 100% probability).

The techniques may further consider a periodic distribution of the future schedule as time passes and visibility progresses, which can facilitate updates to periodic distribution of nodes for an environment such that packets can be rerouted in-flight if a given node obtains newer information (e.g., a newer map of the future) for route computation.

The techniques of this proposal may also find applicability to a variety of Message Queuing Telemetry Transport (MQTT)/DTN environments. Figure 6, below, illustrates an example model that can be evaluated when considering complications that may be imposed by mobility related Internet of Things (IoT) use cases involving mobile nodes where an MQTT client or an MQTT broker may operate in such mobile nodes in order to identify optimum upstream Tempo-Spatial routing paths.

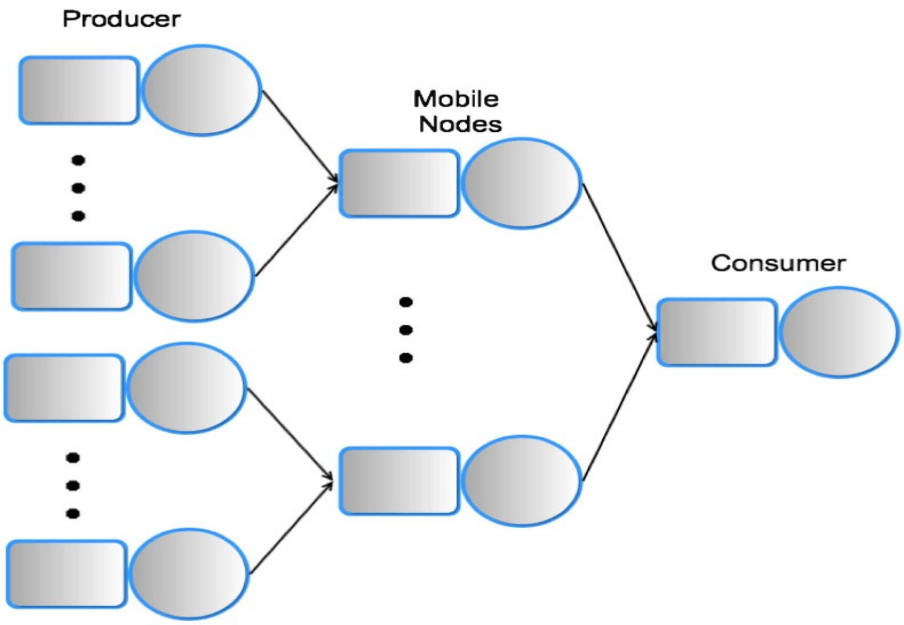

Figure 6: Example MQTT Architecture Involving IoT mobile Nodes

In summary, techniques presented herein propose a foundational "routing to the future" model for mobile DTN nodes that can enable predictable rendezvous among such nodes such that one or more routes along rendezvous points can be computed for an environment while optimizing for the total latency, energy, and chances of delivery based on the probability of the rendezvous to effectively occur in the environment.