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# Survey of Trajectory Based Forwarding and Its Applications

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***Abstract-*** **Trajectory based forwarding is a novel method to forward packets in a dense ad hoc network that makes it possible to route a packet along a predefined curve. It is a hybrid between source based routing and Cartesian forwarding in that the trajectory is set by the source, but the forwarding decision is based on the relationship to the trajectory rather than names of intermediate nodes . the fundamental aspects of TBF are: it decouples path naming from the actual path; it provides cheap path diversity; it trades off communication for computation . these aspects address the double scalability issue with respect to mobility rate and network size. In addition, TBF provides a common framework for many services such as: broadcasting, discovery, unicast, multicast and multipath routing in ad hoc networks. TBF requires that nodes know their position relative to a coordinate system. While a global coordinate system afforded by a system such as GPS would be ideal, approximate positioning methods provided by other algorithms are also usable**

***Keywords-*** **ad hoc networks, trajectory based forwarding, routing, multipath, broadcasting, positioning**

## I. INTRODUCTION

Recent advances in wireless communication devices, sensors, hardware (MEMS) technology make it possible to en-vision large scale dense ad-hoc network acting as high resolution eyes and ears of the surrounding physical space. Examples of such vision include smart dust data spaces, sensitive skin or disposable networks where it is possible that many of the nodes of the network can be sprayed, dropped, mixed in the material or embedded in the infrastructure.

These networks are characterized by a large number of energy-constrained, unattended nodes. Beside the algorithmic aspects dictated by their sheer scale, the emphasis on energy efficient algorithms require that nodes often go into doze mode or sleep mode resulting in a very dynamic net-work topology. These characteristics require us to rethink the way many of the networking functions can be implemented. One of the fundamental networking functions is routing. Routing always has been treated as sending packets along route paths described by a discrete set of points.

MANET community for ad-hoc networks are aimed at resource-rich, relatively stable networks.

In this paper, we propose a new forwarding paradigm, Trajectory based forwarding (TBF) which addresses the issue of scalability and dynamic network topology. This is fundamentally new approach to routing in “dense matter” where the route path is specified and treated as a continuous function as opposed to a discrete set of points. The transition from a discrete view of route paths to a continuous view of route paths is only natural as we move from dealing with sparse networks to dealing with dense networks. The key idea in the approach is to embed a trajectory in the packet and then let the intermediate nodes forward packets to those nodes that lie more or less on the trajectory. Rep-resenting route paths as trajectories are an efficient scalable encoding technique for dense networks. Since a trajectory does not explicitly encode the nodes in the path, it is to a large extent impervious to changes in specific nodes that make up the topology. We believe that trajectories are a natural namespace to describe route paths when the topology of the network matches the topography of the physical surroundings in which it is deployed which by very definition is embedded computing. Here, the physical paths traversed by packets mirror the underlying shape of the physical space that is being queried. Further, forwarding packets along trajectories can be very effective in implementing many networking functions when standard bootstrapping or configuration services are not available, as will be the case in disposable networks where nodes are thrown or dropped to form a one-time use network.

Although Cartesian routing offers the possibility of routing packets based on positions, it does so only on straight lines between source and destination. There are many practical network services that require routing along routes possibly other than the shortest path. One such example is multipath routing, which may be employed by a source to increase bandwidth, or resilience of communication. Routing along the shortest path is not always the best option in wired networks. In sensor networks the same problem manifests itself as potential network partitioning due to battery overuse along popular shortest paths. Communication over alternate paths must be therefore used as a load balancing method in order to achieve more uniform battery depletion. Finally, non straight trajectories are necessary to describe unicast routes in a network where straight line forwarding is not possible due to obstacles, holes in connectivity, or other criteria, such as security requirements.

TBF has a number of features that make it an ideal candidate for a low level primitive in any ad hoc network.

1. It decouples the path name from the path itself. This is the most critical aspect in a dense network, where intermediate nodes between source and destination might move, go into doze mode or fail, thereby rendering a discrete source based path useless.

2. The specification of the trajectory is independent of the name of the destination. This makes TBF usable as a routing support, when the destination is indicated, as a discovery support primitive, when the destination is not known, or as a flooding replacement.
3. It provides cheap path diversity, when compared to flooding based traditional methods of finding alternate paths.
4. It trades off communication for computation, by declaring paths instead of searching them. This is a desirable tradeoff, considering the four orders of magnitude difference between the cost of sending a wireless packet and executing an instruction.
5. It may be assisted by various functionalities available in the nodes. Ideally, each node would be equipped with a GPS receiver, case in which nodes closest to the indicated trajectory will forward the packet. If, how-ever, GPS is not available (such as non line of sight scenarios, or lack of sufficient precision) TBF may use approximate positions given by positioning algorithms that are based on nodes' other abilities to sense their neighbours.

Besides simple unicast, trajectory routing and forwarding have significant advantages for many other important net-work functions such as broadcasting, discovery, multipath, multicast and broadcast, path resilience. In this paper, we focus on issues related to trajectory forwarding in networks with and without the availability of node positions, and identify a number of research challenges related to trajectories in ad hoc network

## II. RELATED WORK

There have been significant efforts to improve routing in both fixed and mobile networks when position is available. Such methods, in which node spatial positions are essential to the method, are branded "position centric". Geographic routing is a hierarchical scheme where each router is responsible for a polygonal region possibly sub partitioned into disjoint polygons assigned to other routers. This routing scheme provides an infrastructure that can be embedded in IP, and can deliver messages to specific geographic regions. Cartesian routing is a greedy method that chooses a next hop that provides most progress towards the destination. It is a particular case of TBF, and both are representative for position centric routing. LAR (Location Aided Routing) is another (position centric) scheme that implements restricted area flooding in order to reduce the cost of discovery when the uncertainty about a destination is limited. It uses a phase of source based routing and a phase of controlled flooding.

Cartesian routing, and other greedy methods derived from it do not guarantee the delivery of the packets. The problem is usually addressed by planar zing the network graph and applying detour algorithms, such as FACE, GPSR, or GOAFR+, that avoid obstacles using the "right hand rule" strategy that work well for straight line delivery.

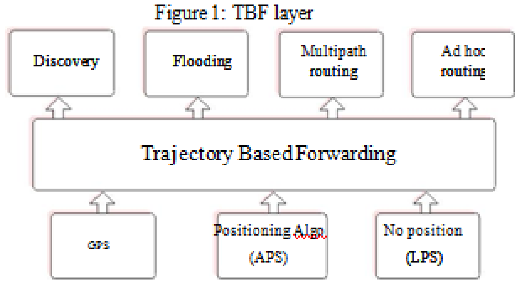
The other big category, inherited from wired networks, is "node centric" - destinations and intermediate forwarding entities are names of nodes. DSR (Dynamic Source Routing) is a form of source based routing used in MANET, featuring a route discovery phase based on flooding, and routes completely specified in packet headers. Term node routing is also a source based method, but uses anchors instead of intermediate nodes. It is close in spirit to our proposed method, but is discrete in the representation of the path. The method may still entail large overheads for long paths that might otherwise have a compact parametric representation.

In order to use position centric approaches, node positions are necessary, but a locations service is also necessary to translate node addresses into coordinates. GLS (Grid Location Service) implements a naming service that allows node centric applications to run on top of geographic and Cartesian routing. A source can find the coordinates of the destination node from the location service and then use geographic or Cartesian routing to route to that destination. Other location services include DREAM, which updates locations with remote communication pairs based on angular drift, and which makes use of Bloom filters to decide if a mobile is in a certain area.

A more recent approach is "data centric", pioneered in which routing is driven by interests, describing the meaning of data transferred. In a sensor network, multipath routing may be useful in providing resilience.

TBF can be used to enhance or complement all the node centric, position centric and data centric mechanisms, or to replace expensive energy-wise parts of them, such as flooding based discovery

Figure 1: TBF layer




## III. TBF DESCRIPTION

TBF is a hybrid technique combining source based routing and Cartesian forwarding but uses a continuous representation of the route. Like in on distance to destination - the measure is the distance to the desired trajectory. Source based routing has the advantage that intermediate nodes are relieved of using and maintaining large forwarding tables, but it has the disadvantage of the packet overhead increasing with the path length. Cartesian routing uses positions to get rid of the routing tables, but defines one single forwarding policy: greedy, along a straight line. Source based routing; the path is indicated by the source, but without actually specifying all the intermediate nodes. Like in Cartesian for-warding, decisions taken at each node are greedy, but are not based

TBF gets the best of the two methods: packets follow a trajectory established at the source, but each forwarding node takes a greedy decision to infer the next hop based on local position information, while the overhead of representing the trajectory does not depend on path length. In a network where node positions are known, the packet may be forwarded to the neighbor that is geographically closest to the desired trajectory indicated by the source node. If the destination node is known, the trajectory followed by the packet might be a line, and the method reduces to carte-sian forwarding. In the general case, however, we envision a larger array of applications including ad hoc routing, discovery, flooding, and multipath routing. Trajectory based forwarding (TBF) requires that nodes be positioned relative to a global coordinate system or a relative coordinate system. The strength of TBF lies in the flexibility of being able to work over a wide variety of positioning systems. In fact, TBF can be seen as a middle layer between global, ad hoc and local position providing services, and many network management services.

### *A. Forwarding methods*

Several policies of choosing a next hop are possible:

- "Minimum deviation": choose the node closest to the curve, with the minimum residual. This policy would favour node $N_2$ and would tend to produce a lower deviation from the ideal trajectory;
- Most forwarding within radius (MFR) , choosing $N_4$ . This policy should also be controlled by a thresh-old of a maximum acceptable residual, in order to limit the drifting of the achieved trajectory. It would produce paths with fewer hops than the previous policy, but with higher deviation from the ideal trajectory;
- Centroid of the feasible set, favouring $N_3$ : the centroid is a way to uniformly designate clusters along the trajectory, and a quick way to determine the state of highly dense networks;
- The node with most battery left; randomly in mobile networks a forwarding policy that might pro-vide better results would be to choose the next hop which promises to advance along the trajectory, or one that is expected to have the least mobility in the fu-ture.

### *B. Trajectory specification/encoding*

There are a number of choices in representing a trajectory: functional, equational, or parametric representation. Functional representation cannot be used to specify all types of curves (for example vertical lines).

Equational representation (e.g. $X^2 + Y^2 = R^2$) requires explicit solution to determine the points on the curve. Parametric representation (e.g. X = X(t), Y = Y (t)) is ideally suited for the purpose of forwarding. The parameter t of the curve is a natural metric to measure the forward progress along the path and can be linked to either length traveled on the curve, or hop count.

Complex trajectories can have multiple components or a given trajectory can be specified as a number of simple component such as Fourier components. The more Fourier components are specified in the packet, the better the accuracy of the trajectory is. There is an interesting tradeoff between the accuracy of the curve and the overhead of specifying the components and interpreting them. Other possibilities of encoding of the parametric curve include compiled form (ready to be executed, as in active networking), or reverse polish notation (ready to be interpreted). In our current implementation on Mica motes, we used the latter, for the increased flexibility.

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## IV. APPLICATIONS OF TBF

Having discussed the implementation details of TBF, we shall now investigate some of the applications that would benefit from an implementation under the TBF framework. There is a wide variety of trajectory shapes that can be used in applications, but a broad classification of trajectories may be into simple or composed. Simple trajectories describe a single continuous curve, and, in the context of routing, are used for unicast. Composed trajectories describe several, spatially different curves. They may also be used for unicast in an anchor based fashion, when a complicated trajectory is described as a list of simpler trajectories. Composed trajectories have a more obvious use in broadcast and multicast, where a unique curve is less appropriate.

A naive broadcasting scheme based on trajectories uses a number of radial outgoing lines that are reasonably close to each other to achieve a similar effect without all the communication overhead involved by receiving duplicates in classical flooding. More generally, a source would indicate the directions and the lengths of the lines that would achieve a satisfactory coverage. Coverage relies on the typical broadcast property of the wireless medium, in which several nodes overhear the packet being forwarded. Recovery from failure often involves multipath routing from a source to a destination. In a sensor network, both disjoint and braided paths are useful in providing resilience. A simple five step discovery scheme based on linear trajectories may be used to replace traditional broadcast based discovery. If unicast communication is modeled by a simple curve, multicast is modeled by a tree in which each portion might be a curve, or a simple line. Distribution trees are used for either broadcasting or multicast routing A source knowing the area to be flooded can generate a tree describing all the lines to be followed by packets in order to achieve complete distribution with minimal broadcast communication overlap.

### A. Unicast routing

The prime application of forwarding is routing. The difference between the two is that forwarding, a trajectory need not have a particular destination. Routing involves not only delivery to the destination, but the entire process that supports the delivery. This includes forwarding, and also building or updating routing tables. In order to route, the position of a given destination node is needed, as provided by a location service, to enable node centric applications run on top of position centric routing.

The other central problem is how to More advantages are brought by TBF for multipath routing, which may be employed by a source to increase band-width or resilience of communication. The key feature here is the cheap path diversity. Using TBF, the source may generate either disjoint paths as disjoint curves, or braided paths as two intersecting sine waves. In networks with low duty cycles, such as sensor networks, longer alternate paths might actually be more desirable in order to increase the resilience of the transmitted messages (concept similar to Fourier decomposition), or to distribute the load onto the batteries. Since there is essentially no route maintenance, each packet can take a different trajectory, depending on its resilience requirements (similar to different FEC requirements). The multiple paths between a source and a destination can therefore be alternated to cheaply achieve load balancing.

### B. Mobility

Mobile networks are a case in which TBF provides a desirable solution due to its decoupling of path name from the path itself. In a mobile ad hoc network, route maintenance for trajectory based routing comes for free since all that is needed is the position of the destination. This is especially true when only the intermediate nodes or the source are moving, and the destination of the packet remains fixed. When the destination is moving, a location service may be used, or the source may quantify its uncertainty about the destination by using a localized flooding around the destination.

### C. Discovery

One of the areas in which TBF is particularly appropriate is quick and dirty implementation of services with-out the support of preset infrastructure. Such is the case of discovery of topology, or of some resource. Many algorithms use initial discovery phases based on flooding in order to find a resource or a destination. Generalizing an idea presented in ,a replacement scheme using trajectories is as follows: possible destinations advertise their position along arbitrary lines and clients C will replace their flooding phase with a query along another arbitrary line which will eventually intersect the desired destination's line. The intersection node then notifies the client about the angle correction needed to contact the server directly. In order to guarantee that the server and client lines intersect inside the circle with diameter CS, it is in fact necessary for the nodes each to send in four cardinal directions.

### D. Broadcasting

Broadcasting is one of the most used primitives in any network, used for tasks ranging from route discovery at the network layer, to querying and resource discovery at the application layer. Its most frequent implementation is under the form of suppressed flooding, which entails each node of the network broadcasting the message exactly once. It is a stateful method, since it requires bits to mark the status of a node - covered or uncovered. The problem with the marking bits is that they have to be provisioned on a per broadcast basis, if several broadcasts are to be supported simultaneously. If only marking bits are used, some global serialization is necessary. For example if one bit is used, one broadcast is supported in the network, and after the settling time (time at which last copy of a message is broadcast), the bit has to be cleared to allow for another broadcast. Suppressed flooding also incurs several other problems: increased communication increased settling, time poor scalability and delivery ratio in congested net-works. Probabilistic flooding addresses some of these problems by flipping a coin each time a node has to rebroadcast the message. This reduces the number of duplicates a node receives, but the method exhibits a bimodal behaviour, meaning that either the broadcast is successful in covering most of the network, or it dies very early, covering only a small portion around the source. While broadcasting is not the main application of TBF, we can provide solutions that address most shortcoming of traditional flooding and of probabilistic flooding. The broadcast achieved by TBF also has an approximate nature, just like probabilistic flooding, meaning that there may be nodes which do not receive the message even under ideal collision free conditions.

## V. CONCLUSION

We presented Trajectory Based Forwarding (TBF), a novel paradigm that makes the transition from a discrete view of the paths to a continuous view of the paths in future dense networks. The method is a hybrid between source based routing and Cartesian forwarding in that the trajectory is set by the source, but the forwarding decision is local and greedy. Its main advantages are that it provides cheap path diversity, decouples path naming from the path itself, and trades off communication for computation. When GPS is not available, TBF may make use of alternate techniques, such as global and local positioning algorithms. It is robust in front of adverse conditions, such as sparse networks, and imprecise positioning. We believe that TBF should be used as an essential layer in position centric ad hoc networks, as a support for basic services: routing (unicast, multicast, multipath), broadcasting and discovery.

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