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Uisce: Characteristic-based Routing in Mobile Ad Hoc Networks

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***Abstract*—The goal of communication in computer networks is the delivery of information to endpoints with certain properties. In wired networks, identities such as IP addresses are used to guide information through a network and the properties of network nodes are mapped to these identities by service discovery mechanisms. In mobile ad hoc networks (MANETs), identities lose their guiding ability because of the dynamism of the topology.**

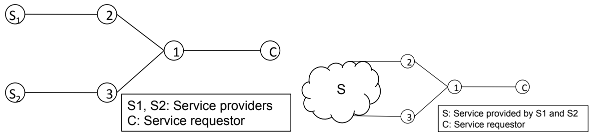
Instead of identities, we introduce a concept called a characteristic, which describes the properties of nodes. Characteristics are disseminated throughout a network, simulating the flow of water streams. Messages are forwarded to their destinations - nodes with given properties - following these characteristics like following a water stream to its source. Characteristic-based routing differs from existing content-based routing in that a characteristic describes features of MANET nodes rather than contents of data messages. A trace characteristic is left by data messages along their forwarding path. Subsequent data messages can be forwarded to the same destination node and reply messages can be delivered back to the sender of data messages following the trace characteristic.

We demonstrate that a characteristic-based approach increases the rate of successful delivery in comparison to existing identity-based approaches in MANETs. Then we analyze the ability of trace characteristics to maintain routes for subsequent data messages in different mobility settings.

I. INTRODUCTION

In current communication architectures, the Internet Protocol (IP) suite provides identity-based addressing and routing at network layer. Service discovery is achieved at application layer by maintaining a mapping between the identity of a node and the services that the node provides. In wired networks, IP address describes the location of a network node, i.e. the subnet that the node is attached to[2]. However, the location of nodes changes frequently in MANETs. IP addresses lose the meaning that they have in wired networks. Rather, they are used as identities to differentiate nodes.

We argue that identity-based end-to-end communication does not suit MANETs. First, identity-based routing is misdirected: it is the properties rather than the identities of nodes that are of primary interest. Second, the topology of a MANET consisting of individual nodes is more dynamic and prone to communication failure than the topology of services in such a network. Shown in Fig.I, S_1 and S_2 provide the same service that the requestor C is interested in. From the perspective of individual nodes (Fig.1(a)), the failure of an intermediate link disrupts the provision of a service; In contrast, from the perspective of service (Fig.1(b)), the failure of an intermediate link has less effect on the provision of the service.



(a) Identity-based (b) Service-based

Fig. 1. Topologies of a MANET

Content-based routing (CBR) has been proposed to address the aforementioned issues of identity-based approaches. Instead of identities, in CBR data messages are routed based on their content and the subscriptions of nodes. Therefore senders and receivers are loosely coupled and communication is less affected by the frequent network changes. A limitation of CBR is that by itself CBR only provides one-way data delivery from content publishers to subscribers. Because the two ends of a communication are loosely coupled, it does not address the issue of delivering data from subscribers back to publishers, i.e. two-way communication is not supported by CBR.

In our protocol *Uisce*, we introduce a concept called a *characteristic*. A characteristic describes information of general interest about a MANET node. It can be service description, as used in service discovery, or features of a node such as type of CPU, battery power, etc. We propose a potential-based approach for dissemination of characteristic information. To establish a two-way communication, a characteristic is left by data messages along the path. Further communication will follow the characteristic towards specific nodes.

II. SERVICE DISCOVERY

Service information includes service name, service description, service type, etc. It is advertised periodically with the IP address of its provider. A database of this information, called a directory, can be used to facilitate communication between service providers and requesters. A service provider registers its information with a directory and a service requester contacts a directory for the IP addresses of providers. The requester then contacts a provider for a service invocation. Based on the existence of directories, service discovery protocols can be classified into three categories: centralized directory-based solution [3], distributed directory-based solution [4], and directory-less solution [1]. Compared to centralized solution, directory-less solution suits more in a dynamic MANET while

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distributed solution achieve a better scalability. [5]. However, regardless of the structure, the service discovery is strongly coupled with IP as a service is associated with an IP address.

III. CHARACTERISTIC-BASED COMMUNICATION

Majority of identity-based routing protocols use the distance of a path, such as hop count and delay experienced, as routing metric. Resource discovery such as service discovery, on the other hand, uses the capacity of resources as metric when selecting providers. Characteristic-based routing uses a potential-based method to combine the two metrics into one to integrate route discovery with resource discovery.

Each characteristic at its source node is assigned a potential value called weight to represent its capacity. The dissemination of characteristic information simulates a water stream: water propagation is driven by potential value, from high to low. And during the propagation, water flows lose their potential value. Multiple streams merge into one at intersection point, form a new stream and propagate further. The higher capacity a characteristic contains, the further it may propagate; the closer to a character source, the higher capacity could be sensed.

Different characteristics may have different form of weight changes during propagation, depending on the nature of the characteristics and the network environment they run through. For example, internet connection is preferable to nodes in the vicinity, while a printing service may function in a much larger area. We introduce three "knob" functions to tune the form of weight changes as a characteristic propagates. Data forwarding is driven by weight gradient. In this way, route selection balances between the distance to a source node and the capacity of a characteristic.

A. Characteristic Flow

Periodically, every node broadcasts its characteristic information. Its neighbours inherit these characteristics and spread them out further during their broadcasts. A node has only the knowledge about the characteristics of its one-hop neighbours.

During the one-hop based propagation of characteristic flows, a *weight cost function* is applied to simulate the weight lost over a link. The capacity of a characteristic perceived by a remote node decreases as the distance to the source node increases. This reduction arises from error-prone wireless links as well as the potential consumption of the resource along the path. Consider the example of internet access, a route that consists of multiple hops will not achieve the same throughput as a single hop communication. The weight decrease at each hop forms a weight gradient to the anonymous sources of a characteristic. Characteristic propagation is driven by weight gradient: the characteristic information can only flow from nodes with higher weight to nodes with lower weight. A predefined constant w_{dif} is given to control this aspect of propagation: a node which contains a characteristic with weight w accepts an incoming characteristic of the same type only if it has a weight no lower than $w - w_{dif}$, see Fig.2.

Multiple sources of a characteristic may coexist in a MANET. Information about various source of the same characteristic will merge when they meet at an intermediate node. The resulting weight of the merged characteristic is computed by *weight fusion function*.

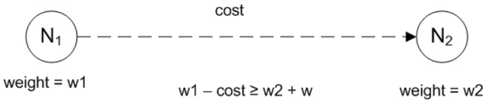


Fig. 2. Propagation

The *weight cost function* and *weight fusion function* describe the inherent behaviour of characteristic flows. However there are also external factors that should affect the flows and eventually future route selection, i.e. link reliability and processing power of an intermediate node. In order to provide the flexibility for a node to affect a characteristic flow that runs through it, we introduce a *cost compensation function*. *Cost compensation function* is applied by an intermediate node of a characteristic flow to reduce the cost along the hop.

1) Function Specification: The *weight cost function* should be a monotonic increasing function of weight since the loss of a strong flow should not be smaller than that of a weak flow. In this paper, we select

$$c(x) = \begin{cases} \lambda e^{\frac{x}{\tau}} + a & \text{if x} > threshold \\ x, & \text{if x} \leq threshold \end{cases} \tag{1}$$

to describe the weight cost. τ,λ and a are parameters to shape the cost function. The $threshold$ is one of the solution(s) of equation (2). It can be intuitively understood as the minimum weight value for a characteristic flow to propagate further.

$$\lambda e^{\frac{x}{\tau}+a} = x \tag{2}$$

The *weight cost function* is applied to all characteristics before they are propagated in hello messages.

If a node hears multiple instances of the same characteristic, i.e. from different neighbours, the weight of its characteristic is calculated by *weight fusion function*. Assume a node is a source of a characteristic with weight w_s ($w_s = 0$ if it is not a source node). If there are n incoming characteristic instances, and each is associated with a weight w_i, we can write the weight fusion function as:

$$\begin{aligned} F(W_n) &= F(w_1, w_2, \cdots, w_n, w_s) \\ &= \max(w_1, w_2, \cdots, w_n, w_s) \end{aligned} \tag{3}$$

In this paper, we specify the *cost compensation function* so to emphasize a characteristic flow that is fused from multiple flows. Denoted as $c^*(n)$, the *cost compensation function* is an increasing function, where n is the number of one-hop neighbours upstream in the characteristic flow. Our assumption is that multiple paths imply more reliability. However, we only discuss the value range of the function since the function can be specified in any other forms:

$$c^*(n) : N \longrightarrow \{0, ..., c^*_{max}\}$$

B. Data Forwarding

When a node receives information about a characteristic, it is able to send data to the anonymous source of this characteristic. Similar to hello messages, the propagation of data messages is driven by weight difference, but in a reverse direction. Data messages are always forwarded from nodes with a lower weight to nodes with a higher weight.

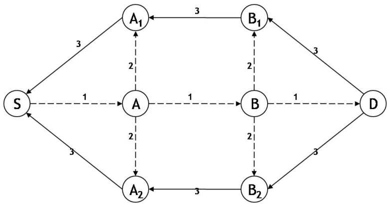


Fig. 3. Trace characteristic: Instead of a single path, a trimmed directed region - a corridor - is formed from D back to S

The data communication is one-hop oriented. A sender has no knowledge about the source of a characteristic but forwards data to one or more promising neighbours which are upstream from it towards the source of the requested characteristic. On receiving data, an intermediate node handles the message for its neighbour, following the same process of the sender. This one-hop communication continues until data finally reaches a source node of with the specified characteristic.

C. Trace Characteristic

As we have argued in section 1, the discovery of a node with interested services and/or features should be decoupled from node id. With the characteristic information disseminated in an ad hoc network, one-way data delivery can be established: data messages can be forwarded to a node of a characteristic.

Once the first message has been delivered, a context of the communication is formed. In certain scenarios, the context may dominate that either one or two ends of a communication require to be identified: further data messages need to be delivered to the same node of a characteristic that received previous data message; a node may wish to reply to the source node on receiving a data message. In these cases, communications are maintained on two specific nodes.

In order to establish communications based identified nodes, we introduce the operation of trace characteristics. A trace characteristic is essentially a characteristic, but is unique among the characteristic space of a network. A node may generate its trace characteristic based on its identifications, such as IP addresses and MAC addresses. We leave the detail discussion of formatting out of this paper.

As shown in Fig.3, the operation of trace characteristics contains three phases: 1) The trace characteristic of node S is inserted into the data message addressed to a characteristic provided by node D. The weight of the trace characteristic decreases at each hop along the path of data messages by the cost function. 2) Each intermediate node along the path record and keep the trace characteristic for a predefined duration T_{trace}. During this period, each intermediate node spreads the trace characteristic through hello message. The trace characteristic propagates as a normal characteristic except that a time-to-live (TTL) field is associated. It can only propagate a predefined TTL hop of distance. In this way, a width of $2 * TTL$ "corridor" is formed, within which characteristic gradient leads to the node S. 3) Node D can thus reply back to node S by addressing to the trace characteristic. If node D wishes further message from node S, it simply insert its own trace characteristic with the reply message back to node s.

# of Nodes	20 - 1000
# of characteristics	2 - 100
Network Area	800*800 m^2 - 4000*4000 m^2
Mobility	Random Waypoint
MAC protocol	802.11g 11Mbps
Transmission Range	250m
Uisce Parameters	Hello Interval: 1-3 seconds Active Characteristic Timeout: 5 seconds

TABLE I
EXPERIMENT SETUP

IV. EVALUATION

We have implemented and evaluated Uisce in OPNET 16.0. In this section, we present statistical results to demonstrate the performance of our protocol.

A. Comparison with IP-base Service Discovery

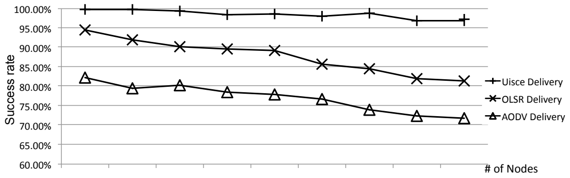
For comparison, we have also implemented a simple service discovery scheme building above IP. OLSR and AODV are used as routing protocol. The implemented service discovery uses distributed directory-based architecture. Service providers register their service to broker nodes. On receiving a request from application layer, a client first sends discovery message to broker nodes. After receiving a reply from a broker node, the client sends requests to all providers of the requested service.

We examine two metrics: one-way delivery rate and service availability. One-way delivery rate is the success rate of one-way data delivery. Uisce is compared against routing protocols with this metric. Service availability is the ratio that a request from application layer being successfully replied. Uisce is evaluated against service discovery protocol with this metric.

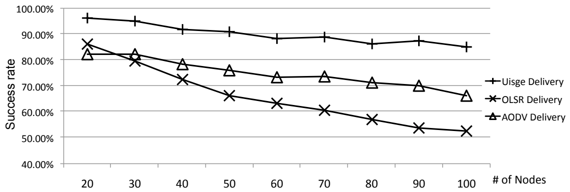
At network layer, we observe from Fig.4(a) that Uisce provides about 5-15% higher delivery rate than OLSR and about 15-25% higher than AODV. More importantly the delivery rate of Uisce remains relatively stable as network size increases. On the contrary, the delivery rate of both AODV and OLSR drops over an increasing network size. Fig.4(b) demonstrates the performance of three protocols over higher mobility. Comparing to AODV and OLSR, the delivery rate of Uisce keeps at a high level in fast mobility scenarios. A high mobility essentially means more frequent link breaks. From Fig.4(b) we can therefore conclude that Uisce endures in high dynamic networks. This result confirms the rationale behind our proposition: the topology of characteristics observes less dynamism of the topology of individual nodes.

B. Maintenance of Two-way Communication

We set up a MANET with 1000 nodes initially located in a random fashion. 10 nodes, denoted as set D, possess a characteristic. 10 other nodes, denoted as set S, deliver data messages that are addressed to the characteristic every 10 seconds. After receiving data messages, nodes of set D reply continuously for 10 seconds. We examine the ability of trace characteristics to lead reply messages back to the source nodes over the duration without any update from S. As we anticipated, most routes break soon after established in single path setting. A trace corridor, however, maintains reply communications at a much improved successful rate over the 10 seconds period that no messages are seen from S. A larger

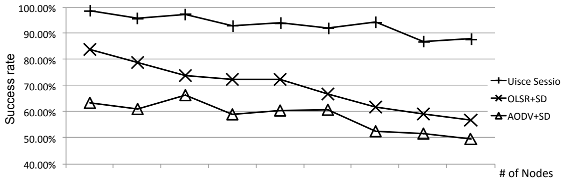


(a) Max Speed: 5m/s

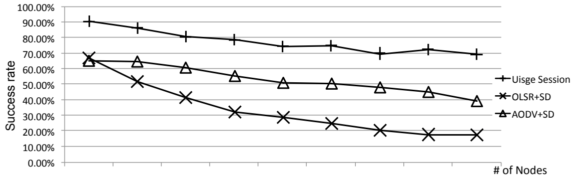


(b) Max Speed: 15m/s

Fig. 4. Successful delivery over network size with different mobility settings



(a) Max Speed: 5m/s



(b) Max Speed: 15m/s

Fig. 5. Service availability over network size with various mobility settings

TTL exhibits a better success rate compared to a smaller TTL value, particularly in a highly mobile network.

C. Effects of Different Cost Functions

The three knob functions control the manner of characteristic dissemination and provides the flexibility of balancing the route metric and the resource metric. Fig.7 illustrates a scenario where nodes are linearly located. Two nodes, S_1 and S_2, are providers of the same characteristic. The weight values along the characteristic propagation are shown below the nodes. The arrows on top show the direction of data forwarding at each node. We vary the value of τ while the rest of the parameters are: $\lambda = 0.4$, $w_{dif} = 4$ and $a = 8$. In the example of 7(a), hop count plays an important role as intermediate would pick the closest characteristic source. In the example of 7(b), service capacity weighs more compared to 7(b). Node 5 and node 6 will select S_1 even it is further than S_2. Node 7 and node 8, however, will choose S_2 as their distances to S_1 are dominant.

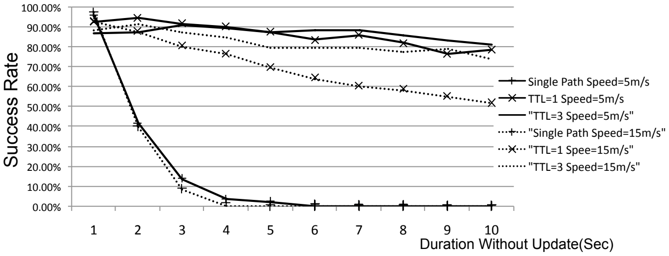
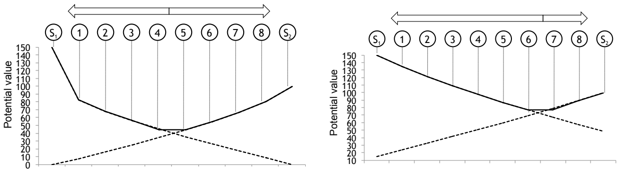


Fig. 6. trace corridor improves drastically the stability of a established route



(a) $\tau = 50$

(b) $\tau = 30$

Fig. 7. Weight value of a characteristic at intermediate nodes: different configurations of the cost function affect the characteristic dissemination and consequently the route/resource selection.

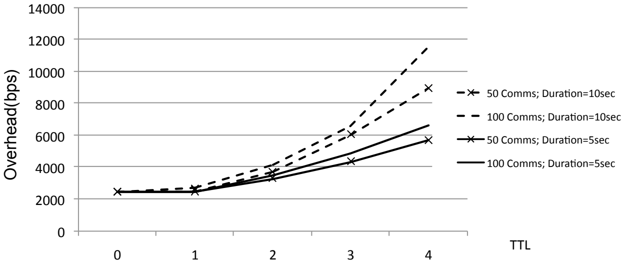


Fig. 8. Overhead Incurred by Trace Characteristics

D. Control Overhead of Characteristic-based Communication

In this paper, we set 192 bits for characteristic information. We evaluate the overhead incurred by Uisce with regard to the width of trace corridor, TTL; the number of communications, N_{comms}. In a network with 1000 nodes and 5 m/s mobility, the overhead for each characteristic is shown in Fig.8.

V. CONCLUSION

In this paper, we propose a characteristic-based routing protocol called Uisce. By using characteristics as network addresses, it integrates resource discovery with routes discovery. In the scenario of requesting for a service or communicating to nodes with certain features, Uisce routes messages to a corresponding characteristics without having to request for the identities of the destinations. This results in an efficient one-way delivery and a high service availability. Data messages may leave trace characteristics along the forwarding paths, which forms a directed corridor. Through this directed corridor, further communication can be routed to specific nodes.

VI. ACKNOWLEDGMENTS

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