SIMULATION OF INTER-UAV COMMUNICATION
REQUIRED FOR COLLABORATIVE TASK EXECUTION

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ABSTRACT

Inter-UAV communication is useful in many areas of human life. At CQUniversity Sydney Campus, we are currently undertaking research to find the ways as to how such communication could take place. When UAVs are employed in farms, for example, they should be able to communicate and negotiate with each other. Furthermore, due to the limited transmission range of these UAVs, they should be able to pass the messages on to the next UAV and so forth until the message is delivered to the router connected to the Internet. Existing commercial UAVs are not capable of undertaking such inter-UAV communications. For this purpose, we use computer simulations to investigate how the messages can be passed efficiently through the UAVs. We have the challenge here that UAVs have limited storage capabilities and battery power. OPNET, a network simulation tool that is widely accepted by the networking community is used for our simulations. We show that our communication method resolves the problem of inter-UAV communication. Such a network with an efficient communication method would help farmers immensely as they would be able to undertake various tasks in their farms covering many hectares autonomously and remotely through their smartphones. This communication method can be extended to other applications of UAVs such as in locating bushfires, crowd surveillance and border patrol where collaboration is required. This paper shows how such inter-UAV communication is possible via a computer simulation.

1 INTRODUCTION

UAVs are being used in many commercial application such as agriculture, rescue, and parcel delivery areas these days and their applications will be very common in the future. The communication between UAVs, known as Inter-UAV communication plays a key role for success in commercial application of UAVs. This communication between UAVs is accomplished with the help of wireless routing protocols. The position of a flying UAV is a crucial factor in choosing an appropriate routing protocol for inter-UAV communication. Though inter-UAV communication appears to be much similar to communication in Mobile Ad hoc Networks (MANETs) and Vehicular Ad hoc Networks (VANETs) there are certain differences as well. For example, in private UAV networks, the UAVs are used for collaborative task execution so that the positions of them would be controlled by the ground station or the other UAVs. Hence, the routing protocols used in MANETs and VANETs will not be efficient in this case.

Previous research on routing, mobility models in UAV communication networks have been surveyed by Guangyu et al (2000). Tarque et al. (2015) also discussed basic routing protocols in their paper and categorised them as static routing, proactive routing, reactive routing, hybrid routing, geographical routing and hierarchical based routing. In an experiment conducted on UAVs communication by Clausen et al. (2003), a dynamic routing protocol Proactive P-OLSR (optimized link state routing) was proposed. In this paper, the authors compared OLSR (optimized link state routing) with proactive P-OLSR over the small fixed wing UAVs. Their experiment shows P-OLSR is a better option and it follows the change in topology without any interruption to traffic flow.

However, in some private applications of UAV networks such as in agricultural farms, the UAVs can travel along predetermined paths or waypoints. As we show in this paper, in such applications, dynamic routing algorithms are not required as they make the batteries run out fast.

For this purpose, we first consider a scenario of an agriculture farm where six UAVs are used to scan and collect field data while using existing position based routing protocols. Then we use our new static protocol on the same six UAV network and analytically compare its routing path with that resulting from the existing position based routing protocols. We use OPNET modeler to simulate the new UAV network employing the new static routing protocol and analyse the results. The simulation shows the smooth data transmission through the UAV nodes.

The structure of the remainder of the paper is organised as follows. Section 2 discusses the existing position-based wireless routing protocols. Section 3 analyses the routing paths formed by major position-based routing protocols in the scenario of our private network. Section 4 deals with routing paths analysis of the new static routing protocol and simulation is discussed in Section 5. Finally, the paper is concluded in Section 6.

2. WIRELESS AD HOC ROUTING PROTOCOL

The routing protocols developed for MANETs have been standardised and are more mature. These protocols have been used in various applications of MANET and VANET communications and subdivided into two categories, topology-based and the position-based wireless routing protocols. The topology-based protocols use link information to transmit data packets from one node to another whereas GPS information is used by the position-based protocols for this purpose. Since the location of all UAVs are known in UAV networks, for Inter-UAV communication, the position-based routing protocol are more suitable. As such, in the following subsection, we will discuss some key position-based routing protocols.
These protocols use the GPS information to forward a packet from one node to another. In these protocols, the source node initiates the packet forwarding to designation node and the position of the destination node is already known to the source node. They are divided into three categories namely nondelay, delay and Hybrid. The summary of these routing protocols are shown in Figure 1.

2.1 VADD (Vehicle-Assisted Data Delivery)

VADD is a delay tolerant network position-based routing protocol. In this protocol, the moving node sends a data packet to a static node only if it has a guaranteed neighbour node. This protocol has three packet modes namely straightway, intersection and destination mode. Straightway mode sends the data packet to next intersection, the packet forwarding is done in intersection mode by the selection of the optimal path, and the packet is broadcast to the destination node in destination mode. This protocol is suitable for multi-hop data delivery. But it faces a large delay in a big network due to rapid topology change (Jing et al., 2008).

2.2 GeOpps (Geographical Opportunistic)

GeOpps is a Delay Tolerant Network (DTN) type position-based routing protocol. The working of this protocol is based on the navigation system. When a node wants to send its data packets to another node, it follows the navigation system to select the next nearest node to the destination and forwards the data packets to that node. In this protocol, a node stores its data packets until the route information to next node is not available. This protocol has high packet delivery ratio. But privacy is a big concern in this protocol due to the navigation system information which is already known to each node in the network (Leontiadis et al., 2007).

2.3 GPSR (Greedy Perimeter Stateless Routing)

GPSR is a non-DTN non-overlay position-based routing protocol for wireless communication. It uses greedy packet forwarding mechanism to send the data packet from source to destination node. This protocol uses the bacon message to select the nearest vehicle. The data packet forwards to the destination node with greedy forwarding method which is used to select the next node. If this method fails then this protocol selects the perimeter forwarding method to choose the next node. The recovery mode of GPSR is active only when the data packet is reached at a local minimum. In the recovery mode, the data packet is forwarded to the node that is nearest to the destination node, and as such, data packet reaches at the local maximum. In this protocol, the sending node only keeps the information of the next hop node, and therefore, the packet forwarding is much easier. But if the network is very large, then the maintenance of the network is a big issue due to outdated of the neighbour table (Krap et al., 2000).

2.4 GPSR+AGF (Advanced Greedy Forwarding)

This protocol is an advanced version of GPSR protocol and it improves the shortcoming of GPSR protocol. It is a combination of GPSR and advanced greedy forwarding method. The data packets of this protocol consist of speed, the direction of the node, overall travel time and processing time. When a source node wants to transmit the data packet to the destination node, the intermediate node are updated about the destination node information. The information of the unreachable node is also easily detectable in this protocol (Naumov et al., 2006).

2.5 PBR-DV (Position-Based Routing with Distance Vector)

PBR-DV is a position based routing protocol with distance vector algorithm. In this protocol, when the data packet reaches local maximum, it uses the ADOV protocol route discovery mechanism. Whenever a node receives the data packet, it checks whether the data is in the range of
local maximum or it is nearest to the destination node. If this is not a case, then the receiver node stores the packet information of the sender node. The receiver node either broadcasts the packet again or sends it back to the node where it comes from (Lee et al., 2009).

2.6 GRANT (Greedy Routing with Abstract Neighbour Table)

This protocol uses greedy routing with an abstract neighbour table (ANT). Every node in the network has the information of its neighbourhood hops. The role of ANT table is to divide the complete plane into different areas and each area has one representative. This protocol uses metrics to choose the next forwarding node. This matrix depends on the multi-hop neighbours and the multiplication of distance between nodes. The main advantage of this protocol is route recovery such that a packet takes less time to recover the route in this protocol (Dhankhar et al., 2014).

2.7 GPCR (Greedy Perimeter Coordinator Routing)

GPCR is an overlay network position-based routing protocol. This protocol is used for inter-vehicle communication for city environment in which the vehicle density is very high. It uses the position parameter to send the data packet to a target node. When a node wants to send their data packets to the target node, it selects the next node which is near to the target node using the position of that node. Each node in the network knows its position details, their next neighbour detail, and the target node detail. This protocol works upon two strategies know as greedy packet forwarding and repair strategy. In this protocol, the information about the junctions and streets is collected from the planar graph instead of the street map and the routing is performed at the junction. The data packet forwards to the destination node with greedy packet forwarding strategy and the repairs strategy comes into the picture when the link is broken (Lochert et al., 2005).

2.8 CAR (Connectivity Aware Routing)

CAR is used for vehicle to vehicle communication for highway vehicle scenario. This protocol works in four modes know as route discovery, forwarding packets, error recovery and path maintenance. In this protocol, guards are used to find the current location of the target vehicle and it binds the location with the help of geographical information. Temporary details of the vehicle are observed by the standing guards in this protocol (Naumov et al., 2007).

2.9 GSR (Geographic Source Routing)

This protocol is based on the route map. In this protocol, the junctions and routes are converted into a graph using the route map. In this graph, the junctions represent the vertices and routes represent the edges. This graph is used to find the shortest path from the source to destination node. The data packet is forwarded from junction to junction. If there is no connection available between nodes, then this protocol uses the greedy forwarding and recovery mode strategy to transfer the data packet between nodes. The packet delivery ratio in this protocol is good as compared to other position based routing protocols but this protocol does not work well in the sparse network (Chen et al., 1998).

2.10 A-STAR (Anchor-Based Street and Traffic-Aware Routing)

A-STAR is a position based routing protocol which works on the overlay network. This protocol is used for inter-vehicle communication in the city networks. In this protocol, the anchor is identified with the help of a street map and the anchor route is calculated with traffic awareness. This protocol uses two maps, static and dynamic, to discover the route in route discovery mode. The static map converts the city map into a graph and checks for the stable route, whereas the dynamic map tracks the information of real traffic. In this protocol, the data packet is transferred through the high connectivity route (Seet et al., 2004).

2.11 STBR (Street Topology Based Routing)

STBR is based on street topology. It works in three states. The first state is known as the master node that is selected on a junction. The second is the slave node that is another communication node on another junction. The third is the forwarding node that is the intermediate node on the junction that lies between the above two junctions. In this protocol, the master node is chosen to check the link availability to the next junction. The master node also works in two levels, via a neighbour node to its direct junction node, and via a neighbour node to its own junction node (Forderer et al., 2005).

2.12 GyTAR (Greedy Traffic-Aware Routing Protocol)

To overcome the local maximum problem, this protocol uses the carry and forward technique. The data packet is forwarded to the junctions with the help of greedy routing strategy. This protocol uses the digital map to send the data packet from source to destination node. Each junction is allocated with a score that is based on the destination distance and density of traffic. The data packet is forwarded to next junction using this score. The junction who gets the maximum score is the junction where the packet is to be forwarded (Jerbi et al., 2006).

2.13 CBF (Contention Based Forwarding)

CBF is a non-beacon-based routing protocol. In this protocol, if a packet is ready to transfer it finds its neighbour with the help of geographical routing. The data packet is forwarded to the directly connected neighbour node. This neighbour node takes a decision about the packet forwarding with the help of packet information. Each packet contains the information about the node position where the packet comes from, the node ID, destination and the packet ID. This protocol saves a lot of bandwidth as a beacon message is not used for packet transmission (Füßer et al., 2003).

2.14 To-Go (Topology-assist Geo-Opportunistic)

This is a hybrid approach protocol which combines beacon and non-beacon-based routing protocols. It is based on geographical routing in which the target node is identified with the help of topology knowledge. Each data packet sending node has this topology knowledge. This protocol delivers better performance in a high-density network. It uses the opportunistic forwarding technique to transfer the packet, therefore, the packet delivery ratio always becomes higher in this protocol. All nodes are connected to each other so there is no hidden terminal problem in this protocol (Lee et al., 2009).

2.15 GEO DTN + NAV (Geographical DTN with Navigation)

This is also a hybrid approach that combines DTN and non-DTN position-based routing protocols. This protocol works in two modes, DTN and non DTN. The change of
mode depends on the connectivity of the nodes and other issues, such as how many nodes are traversed by a data packet, node direction, and destination node. This protocol uses Virtual Network Interface (VNF) to provide the information about the forwarding node and the route node (Cheng et al., 2010).

3. ROUTING PATHS ANALYSIS OF POSITION-BASED ROUTING PROTOCOLS

All position-based routing protocols depend on the GPS system that provides the location of nodes. This location helps to select the next neighbour node in a communication path through which a packet is forwarded to its destination node. In this section, we apply the major position-based routing protocols to the scenario of our agriculture farm shown in Figure 2 to trace the path from source to destination. In this scenario, six UAVs are used to scan and collect the data of the entire farmland. UAV1, UAV2 and UAV3 fly along the top edge of the rectangle, and UAV4, UAV5 and UAV6 fly along the bottom edge so that their final positions will be one hop to the right of the initial positions. Depending on the maximum transmission rate of each UAV, we assume that a UAV can process the information of at most five other UAVs and the communication range of a UAV allows it to send data only to the adjacent neighbour UAV.

Figure 2 – Agriculture farm UAV network

We considered all the position-based protocols discussed above and found the optimal path from the source to destination. The result is shown in Table 1.

Table 1: Paths used by position-based protocols

<table>
<thead>
<tr>
<th>Source -&gt;Destination</th>
<th>Paths used</th>
</tr>
</thead>
<tbody>
<tr>
<td>UAV 1-&gt;GS</td>
<td>UAV 1-&gt;UAV 4-&gt;UAV 5-&gt;UAV 6-&gt;GS</td>
</tr>
<tr>
<td>UAV 2-&gt;GS</td>
<td>UAV 2-&gt;UAV 5-&gt;UAV 6-&gt;GS</td>
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<tr>
<td>UAV 3-&gt;GS</td>
<td>UAV 3-&gt;UAV 6-&gt;GS</td>
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<tr>
<td>UAV 4-&gt;GS</td>
<td>UAV 4-&gt;UAV 5-&gt;UAV 6-&gt;GS</td>
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<td>UAV 5-&gt;UAV 6-&gt;GS</td>
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<tr>
<td>UAV 6-&gt;GS</td>
<td>UAV 6-&gt;GS</td>
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</table>

The above table gives very simple paths as the number of UAVs are very few. In private networks, as each UAV can cover a large area before recharging, only a few UAVs are needed. Therefore, these protocols are not the best choice for inter-UAV communication in private networks.

4. ROUTING PATHS ANALYSIS OF THE NEW STATIC ROUTING PROTOCOL

In our static routing protocol, the routing path is specified by the ground station and it is the shortest path from the source to the destination. Each UAV has a static routing table which stores the information about the next hop neighbour. This table cannot be updated during the communication. The path followed by the information flow in static routing protocol is shown in table 2.

Table 2: Paths used by the static routing protocol

<table>
<thead>
<tr>
<th>Source -&gt;Destination</th>
<th>Paths used</th>
</tr>
</thead>
<tbody>
<tr>
<td>UAV 1-&gt;GS</td>
<td>UAV 1-&gt;UAV 4-&gt;UAV 5-&gt;UAV 6-&gt;GS</td>
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<td>UAV 6-&gt;GS</td>
<td>UAV 6-&gt;GS</td>
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As we can see both the tables are identical. However, the static routing protocol has no routing protocol overhead as the path is pre-defined. On the other hand, the position-based dynamic routing protocols produce routing overhead due to routing information exchange. The packets experience more delay at each forwarding node to process the routing table to select the next packet forwarding node.

5. SIMULATION

In our simulation testbed, we used the same agriculture farm scenario in which UAVs are flying and sending the captured data of the whole farm. These messages are relayed from one UAV to another and finally, to the ground station as shown in Figure 2.

We use OPNET modeler 17.5 to simulate this network. The simulation scenario is shown in Figure 4.

Figure 4 – Simulation scenario in OPNET

Each UAV in this network generates traffic and sends to the server. The results of this simulation are shown in Figure 5 below.
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6. REFERENCES
Prabhu Jyot Singh was born in Bikaner, India, in 1985. He received the B.E. degree in Computer Science & Engineering from the University of Rajasthan, Rajasthan, India, in 2007, and the M.S. degree in Advanced Computer Science from the University of Leicester, Leicester, U.K, in 2010. In 2012, he joined the Department of Computer Science & Engineering at Manda Institute of Technology, Bikaner, as an Assistant professor, and in 2014. At present, he is a Ph.D. candidate in Business and Informatics at the Department of Engineering & Technology, CQUniversity, Sydney Campus. His current research interests include communication protocols for UAVs. He undertakes his PhD research under the guidance of Dr Rohan de Silva who is his principal supervisor. Dr Indra Seher acts as his associate supervisor.

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