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Multi-greedy geographic packets forwarding using flow-based indicators

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Abstract

The MANET packet routing method of geographic greedy forwarding involves the selection of distance reducing intermediate relays towards a destination. The efficacy of the greedy methods differs and varies; nevertheless, the algorithms are similar and process the same data at a forwarding node. Their commonalities potentially allow the online assignment of different methods for more efficient progress forwarding in heterogeneous MANET environments. We define a multimethod *multi-greedy* packet forwarding approach in this paper. Using the IPFIX packet flow measures, we demonstrate the multi-greedy scheme for the performance of repetitive packet routing tasks that permit exploration-exploitation application. The flows report reveal the optimal efficiency of each base greedy method in each flow which aggregates to the multi-greedy design. In comparison to the base methods, the case multi-greedy methods show considerable performance improvement in PDR, hop-count, and delay measures.

Keywords: mobile environments, wireless communication, routing protocols, network, greedy packet forwarding.

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1. Introduction

The mobile ad hoc network (MANET) geographic packet routing method uses greedy forwarding algorithms and nodes' neighbour locations data to select relays that progressively reduce packets' Euclidean travel distance towards a destination. The classic greedy methods include Nearest Closer (NC), Compass Routing (CR), GREEDY, Nearest with Forwarding Progress (NFP), and Most Forward within Range (MFR) [1]. The geographic forwarding approach is also known as location-based, position-based, or geometric routing. In general, the geographic method is most useful for highly dynamic MANET environments where nodes change position frequently. The use of GPS or other location service enables the nodes to keep knowledge of their location coordinates, which they also disseminate to their respective immediate neighbours through beacon messaging. Packet headers provide nodes with the destination location information. Since only the nodes' extant coordinates data are required for routing computations, the location-based method is known to scale quite well in networks exhibiting frequent topology changes. In this paper, we use the terms of method, metric, and algorithm interchangeably when addressing the greedy forwarding applications.

The classic greedy methods mentioned earlier on have been extended and hybridized in various ways to enhance efficient and successful packet forwarding in geographic routing [1] [2]. For example, the GREEDY and the CR methods are constituents of the hybrid GREEDY-COMPASS [3] metric, which is shown to improve successful packets delivery. In some cases, the enhanced greedy method incorporates a non-geometric measure. For example, the *Cost-to-Progress Ratio* (*CPR*) metric defined in [4] is designed with the additional objective of balancing nodal loads. There are differences in the greedy methods' effectiveness, which depends on the topology of the routing environments. However, a commonality among the greedy

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methods is that they perform quite similar geometric computations that also utilizes same neighbour positions data. Indeed, the greedy metrics can easily be used alternately during a multi-hop routing process. This alternating possibility motivate our proposal for the design of a multimethod *multi-greedy* scheme for improving packets forwarding efficiency over heterogeneous MANET. Our contributions in this paper are:

- the introduction of a multi-greedy approach in geographic MANET routing for enhancing the efficient performance of progress forwarding and improving successful packet delivery rates.
- the demonstration of an example multi-greedy forwarding scheme using the packets flow IPFIX network characteristics indicator.

In section 2 we describe the multi-greedy forwarding approach. Next, in section 3, we show an example application of the multi-greedy method. In section 4 we provide a review of related literature, while section 5 concludes the paper.

2. Multi-greedy forwarding

2.1. Greedy forwarding metric characteristics

A MANET geographical routing node that has packets to forward uses the greedy method to choose from among its current neighbours a next relay that is closer to the destination than itself. Examples of the geographic routing protocols that use the greedy forwarding technique are the Greedy Perimeter Stateless Routing (GPSR) protocol [5], the GeoDTN+Nav [6], and the Angular Routing Protocol (ARP) [7]. Figure 1 illustrates a greedy forwarding step for node *c* that has transmission radius *r*. Node *c* must select a neighbour *x* as the next relay in the *progress region* towards the destination *d*. The greedy methods' computations consist of random and deterministic schemes [3] [8]. Fundamentally, any relay node selected must reduce the Euclidean distance remaining for the packet to travel, satisfying $|\overline{xd}| < |\overline{cd}|$. However, a generally inherent greedy forwarding failure problem, termed *local minima* or *void*, occurs when a node with packets to forward has no neighbour closer to the destination than itself; in which case the packets may be dropped, or some remedial action taken [7] [6]. In this paper, we focus on improving progress forwarding and do not address the void problem.

In the illustration of Figure 1, if the node *c* uses the selection metric of GREEDY, $min_{dist}\{|\overline{xd}|\}$, then x_1 shall be the next relay node chosen. The GREEDY computation chooses the neighbour with the minimum distance to the destination. As another example, the utilization of the CR metric, $min_{angle}\{\angle xcd\}$, will lead to x_2 as the next relay choice. The CR choice is the neighbour node enclosing the minimum angle between a line $|\overline{xd}|$ and the line $|\overline{cd}|$. A goal of the CR method is to minimize the total distance that packets must travel. The reader may consult texts such as [1] [3] for more information on the performance modes of the basic and the variants of the greedy forwarding algorithms. The greedy forwarding step is repeatedly performed at each relay node until the packets' destination is reached.

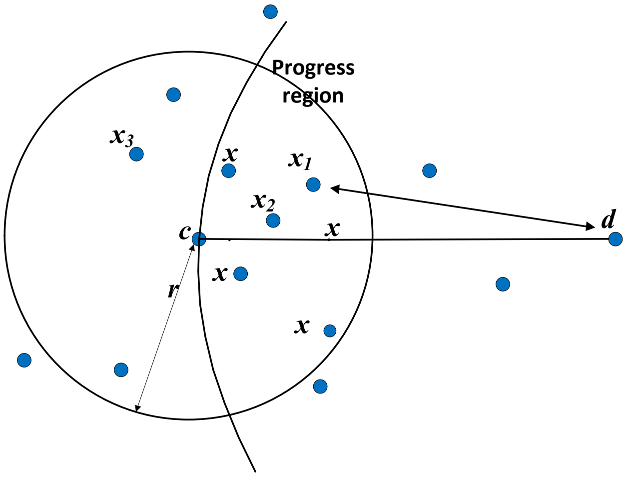

Figure 1. An instance of the deterministic greedy decision-making by a forwarding node *c* choosing a neighbour *x* to relay packets toward the destination *d*. (adapted from [1])

We note the following about the greedy forwarding methods:

- The greedy methods, including the different variants, are intrinsically and structurally similar algorithms. Moreover, whichever method is employed at a node, the same neighbour knowledge data is utilized in the computations.
- The performance efficiency of the different greedy algorithms depends on the underlying MANET topology. For example, the PDR performance outcomes of the ELLIPSOID method [9] dwindles quite significantly when the network's nodes density is high [10]; but it outperforms most other basic methods in moderate conditions.
- The greedy forwarding metrics can be alternately used within the casing of any geographic routing protocol. For example, although the GPSR [5] protocol is designed with the GREEDY metric, it can be re-equipped with any other efficient one. This flexibility creates the opportunity for efficiency-aware adaptive greedy forwarding. Hence, a geographic protocol's implementation at a node may independently and alternately use different optimal greedy metrics in consonance with the changing topology characteristics of a MANET.

2.2. Multi-greedy forwarding formulation

The stated characteristics of the greedy metrics can allow their usage alternately while performing a packet routing task. At different points along a multi-hop forwarding path, the most suitable greedy method is assignable to efficiently perform the subsequent selection of a next relay neighbour. It follows that such a multimethod multi-greedy packet forwarding procedure is the application of multiple greedy algorithms $\{x_1, \ldots, x_n\}$ that are assignable and re-assignable sequentially, based on relative optimal efficiency values of each method, to perform a multi-hop MANET geographic routing task. At each stage or hop(s) level of forwarding, a most efficient method x_j is employed. There are two categories of forwarding method(s) assignment:

(i) Single hop assignment
The single-hop assignment level is fine grain where, for example, each relay node independently decides its greedy forwarding method of choice. An assumption, in this case, is that the routing terrain is mostly heterogeneous.

(ii) Multiple hops assignment
The multiple hops assignment level is where a greedy forwarding method may be repeatedly used over a contiguous set of packet relays based on an efficiency policy, such as flat routing over a homogeneous network segment.

Hence, a multi-greedy packet forwarding optimization function:

$$\underset{x_j \in x}{optimize}\, y = f(x) \quad (1)$$

addresses some *maximize* or *minimize* objective measure, such as the PDR, hop-count, throughput, etc. Each optimization subfunction:

$$y_i = f_i(x_1, \ldots, x_n), i = 1 \ldots m \quad (2)$$

involves the use of the most efficient greedy method(s) for that part. For a single-hop assignment:

$$f_i(x_1, \ldots, x_n) = \vee_1^n x_j \quad (3)$$

produces a specific method x_j to use in the next relay selection. For a contiguous multiple hops assignment:

$$f_i(x_1, \ldots, x_n) = \wedge_1^m (\vee_1^n x_j) \quad (4)$$

produces a sequence of m number of x_j elements that are to be applied one after the other.

The example application of multi-greedy forwarding that we describe in the following section is based on the multiple hops' assignments of the relevant greedy methods.

3. An example implementation of multi-greedy forwarding

In this example, we use packets flow measures and the exploration-exploitation task performance approach to define some multi-greedy forwarding applications.

3.1. An exploration-exploitation multi-greedy forwarding application

The performance of repetitive path search tasks can be improved by exploratory learning of the search environment to determine the most efficient search method for use in subsequent exploitative task engagements [11] [12]. For an *exploration-exploitation* procedure, the network topology should be in a steady-state over the routing task performance period. The period over which a MANET's snapshot is relatively in a steady state determines the extent to which a purposely repeated routing action(s) can yield consistent results. When feasible, the base greedy forwarding methods could be evaluated over the specific routing environment during an exploration phase, while the collection of methods found to be optimal in the different parts of the terrain are to be assigned in a multi-greedy fashion for subsequent efficient exploitation performance(s).

3.2. Greedy metrics used in the experiment

We used two basic and a composite greedy method in designing the multi-greedy example that we demonstrate. Note that any of the existing several variants and hybrids of the greedy forwarding methods can be employed in a multi-greedy forwarding scheme. The following base greedy methods that were used in our experiment have shown higher levels of PDR performance, which is the objective that we choose to maximize in the example multi-greedy forwarding scheme.

(i) GREEDY [13] - is a popularly employed metric in geographic routing protocol designs. The metric simply selects a next-hop that is closest to the destination from among the neighbours of a forwarding node. As shown in section 2, its distinguishing computation metric for selecting the next relay with minimum distance is $min_{dist}\{|\overline{xd}|\}$.

(ii) ELLIPSOID [9] - excels in PDR performance under moderate network density conditions; although its performance has been found to deteriorate in high densities [10]. The ELLIPSOID metric, which we use here in 2D, derives its name from the Ellipsoid protocol [9] that is designed for 3D routing. The ELLIPSOID metric is $min_{dist}\{|\overline{cx}| + |\overline{xd}|\}$.

(iii) GREEDY-COMPASS [3] - is a hybrid composite of two basic methods, GREEDY and CR. Its authors [3] showed that it overcomes void failures. The method first shortlists two neighbour candidates using the CR method. An *above*, $min_{angle}\{\angle x_a cd\}$, and a *below*, $min_{angle}\{\angle x_b cd\}$, neighbours are thus selected on the opposite sides of the $|\overline{cd}|$ line (Figure 1). GREEDY-COMPASS finally selects the next relay from the two candidates using the GREEDY metric $min_{dist}\{|\overline{x_a d}|,\ |\overline{x_b d}|\}$.

3.3. Multi-greedy performance based on packets flow characteristics

We have observed the potential of the IP Flow Information Export (IPFIX) protocol tool for use in characterizing the efficacy of routing methods in a network [14] [15]. The *flow monitor* is a network performance measurement tool that detects sessions of network packet flows emanating from some source(s) toward some destination(s) and exports the aggregated report [14]. A *flow* is tagged based on packets that have common data labels such as port number, source, and destination addresses, timestamps, etc. Flow monitoring has been described as a robust alternative to the traditional method of packet capture that is used in analyzing network performance indications. A network's characteristics information that flow-based measures provide includes bitrates, packet loss ratio, delay, etc. [16]. A module that implements packets flow monitoring is integral to the NS-3 simulator that we used for the evaluation of our proposal [16].

We address progress greedy packet forwarding, excluding void recoveries. Each of the base greedy methods, e.g. GREEDY, is to be evaluated for optimal efficiency in successful packets delivery over a routing period. We consider the unicast routing and the related packets flow characteristics between a pair of endpoints. We use the 'packets successfully received' at the destination characteristic in each flow to differentiate the performance of the greedy methods. The method that has the highest number of packets received at the destination endpoint is considered optimal for that flow. Subsequently, we develop the multi-greedy performance execution file containing a sequential list that associates each flow with an optimal greedy method. We do not measure the hop-by-hop occurrence of events within each packets flow, nor do we consider overhead costs. The overhead costs evaluation procedures relating to exploration-exploitation routing performance is treated in [12].

We compare the average PDR performance outputs of both the base greedy methods and the multi-greedy types. Also, we take cognizance of the related average hop count and delay measures. Note that the multi-greedy methods are transient, as their formulation depends on which methods a practitioner combines for a packet routing task performance. We designate each multi-greedy method using its constituent methods' names concatenated with the symbol '~'. For example, the multi-greedy method GREEDY~GREEDY-COMPASS consists of the GREEDY [13] and the GREEDY-COMPASS [3] base methods.

3.4. Simulation environment

We conducted a performance comparison of the greedy forwarding methods and the multi-greedy types using the NS-3 simulator [16] [17]. Table 1 shows the parameter settings of the simulation environment. We performed unicast 512 bytes CBR packets transmission from a single source to a single destination over multi-hop connections. The network contains 110 mobile nodes that have a moving velocity of 0-15m/s over an area of 1100m^2. The node degree average is 17. The transmission range of each node is 250m. The simulation durations are 200, 600, and 1000 seconds. We further performed simulation for the periods 1400, 1800 and 2200 seconds for the case of evaluating a multi-greedy performance trend. We used the GPSR [5] protocol as the primary geographical routing protocol for hosting the greedy metrics. We disabled the void recovery mode of the GPSR.

Table 1. Simulation Parameters

Parameter	Value
NS-3 simulator	v. 3.23
Simulation time	200s, 600s, 1000s, 1400s, 1800s, and 2200s
Data packet size	512 bytes
Traffic application	CBR unicast
Number of nodes	110
Simulation area	1100m^2
Average node degree	17
Transmission range	250m
Node speed	0 - 15m/s

3.5. Results and discussion

At the end of each simulated exploration period of running a base greedy method, the IPFIX flow tool [14] exported performance output for the routing session. Similarly, we simulated the exploitative multi-greedy sessions. Each simulation involving the base greedy and the multi-greedy methods for the duration of 200s, 600s, and 1000s, respectively generated 371, 886, and 1047 flows. Our reason for taking evaluation measures for three different durations is to determine whether the task exploration period or even the number of flows generated, has any influence on successful packet delivery outcomes for all the methods. The similarity in the number of flows for each period, irrespective of the base greedy or even multi-greedy method involved, enhanced the per-flow comparison assessments. For example, in the 200s period runs, we could isolate which method performed best in each of the associated 371 flows. This further enhanced the assignment of the most efficient base greedy method to each flow. Moreover, we could conveniently compare the performance results of all the methods.

The charts in Figures 2, 3, and 4 all show comparisons of the PDR, hop-count, and delay performance outcomes for the three greedy base methods and the multi-greedy types. The basic greedy methods are:

- GREEDY [13]
- ELLIPSOID [9]
- GREEDY-COMPASS [3] (G-COMPASS)

while the related multi-greedy formulations are:

- GREEDY~ELLIPSOID (GE)
- GREEDY~GREEDY-COMPASS (GGC)
- GREEDY~GREEDY-COMPASS~ELLIPSOID (GGCE)

The relativity in the performance trends of the PDR measures (Figures 2, 3, and 4), as seen across and within the charts, are similar for all the methods, including the multi-greedy types. This implies that any arbitrary and fair sampling period suffices for the exploratory assessment of the base greedy methods while running the exploitative multi-greedy forwarding over the same period should yield commensurate performance improvements. In general, the multi-greedy methods showed improved PDR performances compared to the base greedy types. But in some cases, the GREEDY-COMPASS base method showed better performance than the GE multi-greedy method. The GGCE method showed overall superior performance.

The multi-greedy method of GGCE outperformed its constituent types as well as the other two multi-greedy methods in the PDR measures. For example, the GGCE in the period 1000s show a PDR of 66.96 in comparison to 59.51 of the popular GREEDY method. Also, its hopcount and the delay measures reduced significantly for the 1000s duration execution compared to the 200s. Therefore, in terms of optimum PDR performance, the GGCE formulation can be considered the choice for use in repetitive forwarding tasks regarding this packet routing scenario.

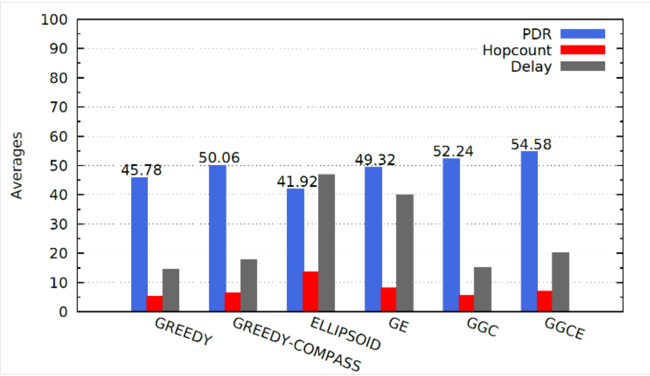

Figure 2. The 200s duration (371 flows) performances for the greedy and the multi-greedy forwarding methods.

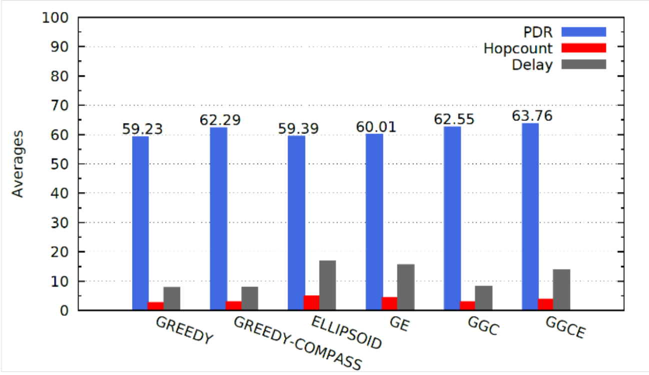

Figure 3. The 600s duration (886 flows) performances for the greedy and the multi-greedy forwarding methods.

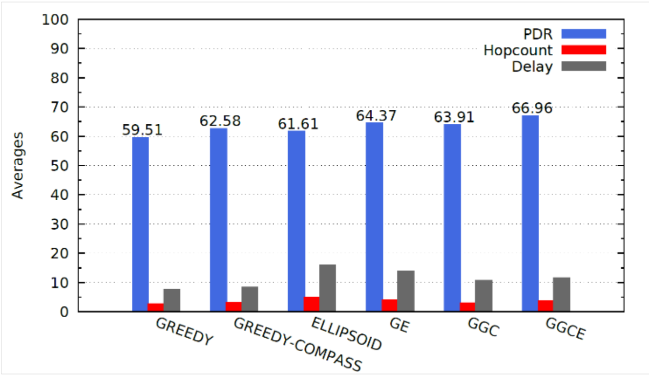

Figure 4. The 1000s duration (1047 flows) performances for the greedy and the multi-greedy forwarding methods.

Figure 5 shows the GGCE's trends of performance in the average PDR, delay and hopcount measures for the execution periods extending from 200s to the 2200s. Despite slight variations over the range, the PDR showed a rise from about 50% and remained relatively high above 60%; while the delay and the hopcount dropped and remained low at around the 10 seconds lapse time and 5 hops level respectively. Therefore, using the GGCE multi-greedy method for exploitative task performance in this routing scenario, especially in the long-duration cases, leads to highly improved PDR, hop-count, and delay measures. The same pattern of performance is found for the GGC and the GE methods, but to save space we do not show their related charts.

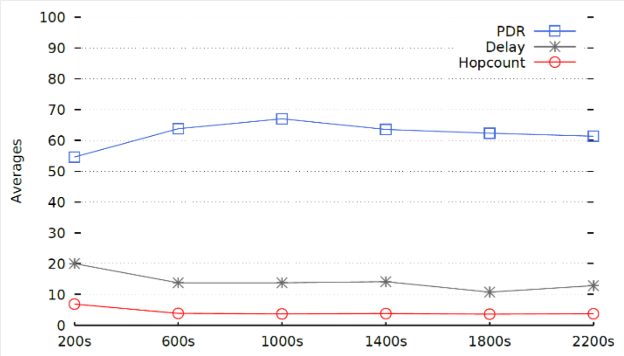

Figure 5. The GGCE multi-greedy method performance for different forwarding durations

Figure 6 shows the differences in the *expected* versus the *actual* successful packets' delivery for the multi-greedy methods of GGC, GE, and GGCE. These are akin to exploration discoveries and the follow-up exploitation outcomes. The expected values are based on the computed per-flow basic greedy methods' optimal performances that we sequenced from the exploration outputs; while the actual values are the exploitation performance outputs of running the multi-greedy methods. In each comparison case for the three methods, there is a slight average drop of about 2% in the actual packets successfully delivered, which is quite tolerable considering MANET vagaries.

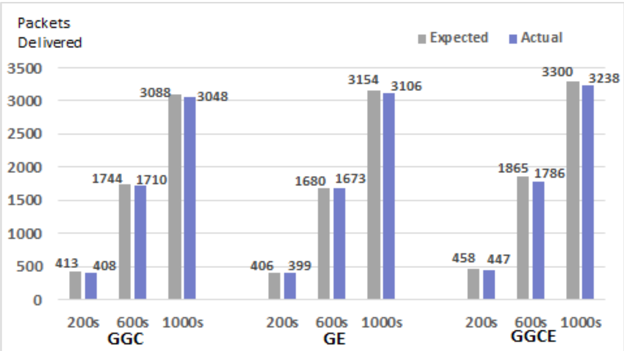

Figure 6. Multi-greedy methods PDR performances, expected versus actual.

4. Related works

The multi-greedy approach that we propose is directed at leveraging the efficiencies of the different existing greedy metrics for improved practical applicative use in progress geographic forwarding over heterogeneous MANET. The literature has addressed the efficiency issues of greedy forwarding using the 'trade-off' and the 'switching' of methods approaches. For example, the GREEDY-COMPASS [3] metric is a trade-off composition of two base greedy methods, the GREEDY and the CR metrics. Some trade-offs combine the greedy measure with some other non-greedy geometric measure, e.g. the GreedyInSector metric that gives the next relay selection priority to a designated sector of the forwarding node's transmission area [8]. The other trade-off types are hybrids that combine the greedy metric with some non-geometric measures [2], such as packets transmission overhead costs [4]. On another hand, the literature has presented hybrid forms that switch the greedy methods for adaptive performance. The GPSR [5] and GeoDTN+Nav [6] are examples of the greedy protocols that adaptively handle recovery from the void or network partitions by switching with other forms of geometric algorithms. The GPSR for instance uses a graph planarization approach with an accompanying perimeter routing method for recovery from voids. The Angular Routing Protocol (ARP) [7] is a sole example of the geographic protocols that switches between two base greedy methods. ARP uses the GREEDY metric for normal progress forwarding while its other greedy metric, CR, handles recovery from void failures. The CR metric can select from the non-progress neighbours, such as x_3 in Figure 1, through which progress forwarding can be re-directed. A significance of the above-mentioned protocols is that they respond spontaneously to any forwarding void or network partition encounters during packet routing. The multi-greedy progress forwarding method that we proposed may similarly be performed with spontaneous adaptation to varying heterogeneous network conditions.

The multi-greedy forwarding example that we presented follows the exploration-exploitation task performance paradigm. The works in [11] and [12] show the benefits of exploring the environment of a repetitive path search task to isolate and apply the most optimal path search method in future performance(s). Accordingly, the exploration performance part enables a search agent to learn the network's embedded graph type and classify the environment for appropriate optimal search method assignment. In [11], the authors compared the relative efficiency of the *depth-first search* method and those of its positional and directional variants for packet routing task performance capacities over the Delaunay and random graphs. A similar study that is described in [3] show that the greedy forwarding methods of GREEDY and CR exhibit varied performance efficiencies over the Delaunay and random graphs. Hence, when the routing environment is known, an optimal search method could be appropriately assigned. The study in [12] addresses the relative costs issues of the exploration-exploitation path search approach and generally recommends this approach for efficiency in performing tasks of repetitive nature. The multi-greedy example that we showed does not depend on embedded graph learning, but it is based on the packet forwarding performance assessment of the applicable greedy methods over a specific environment. An advantage of the example that we presented is that it avoids the difficulty of classifying and associating optimal greedy methods to the embedded graphs of the MANET environments, which practically exhibits diverse topologies including the highly dynamic types. But a disadvantage is the need to often perform exploration assessments of a handful of multiple greedy methods whenever an unknown environment of path search task is proffered.

5. Conclusions

The multi-greedy method that we presented in this paper aims at improving geographic greedy progress packet forwarding in heterogeneous MANET. Progress-based greedy algorithms are utilized in geographic routing to perform the selection of multi-hop relay nodes, which must successively move packets closer to the destination until it is reached. However, each greedy method performs optimally in specific environments. The multi-greedy scheme involves the application of multiple greedy metrics that are sequentially applied or re-applied to packet forwarding based on the optimal efficiency of each method along the routing terrain. The implementation example that we presented in this paper is task-specific, which uses the IPFIX packets flow network characteristic indications to assess the greedy methods' forwarding performance. Exploration of the forwarding task must first be performed, where the applicable greedy forwarding methods are evaluated for optimal capacities. We associated each flow with a most efficient base greedy method and then executed the pattern as the multi-greedy scheme. In comparison to the constituents, the formulated multi-greedy methods of GE, GGC, and GGCE showed improved PDR, as well as relative reductions in hop-count and delay measures. In future work, we plan to investigate multi-greedy progress packet forwarding based on spontaneous reactiveness to real-time network topology characteristics, through using conditional measures such as node density or degree centrality values.

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