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A grid-based cooperative QoS routing protocol with fading memory optimization for navigation carrier ad hoc networks

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ABSTRACT

Cooperative QoS routing (CQR) protocols have the potential to provide scalable information delivery in multi-service network application. However, CQR approach in harsh environments, in terms of long-range transmission, high dynamic topology, and three-dimensional monitor region, is still an open issue. In this paper, we propose a novel grid-based routing approach, namely FMCQR protocol, to guarantee QoS-aware routing for heterogeneous services in above harsh environments. Our approach is explored by the synthesis of three kernel features. First, a grid-based route model is developed on the basis of two key points, i.e., Three-dimensional Geographic Grid (TGG) space and Controlled Virtual Node (CVN). Hereinto, TGG provides a refined virtual addressing space; CVN, basically a distributed cooperative strategy within TGG border, forms the intra-TGG nodes into a virtual MIMO agent, thus the three-dimensional high dynamic topology can be transferred into a CVN-based stationary topology in TGG space. Second, a QoS routing mechanism, namely CQR, is introduced to guarantee QoS-aware route for heterogeneous requests with the assist from CVN-based metrics, and achieve the route discovery in unknown environments by switching between relay-destination (RD) and source-relay (SR) searching algorithms. Third, a novel Fading Memory Optimization (FMO) algorithm, based on Ebbinghaus memory principle, is designed to further enhance the route efficiency. Finally, extensive simulations are conducted to assess the effectiveness of the above features, compared to related typical routing protocols, our approach has better convergence and better QoS in terms of successful delivery ratio, average delay, average link overhead, and normalized routing distance.
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1. Introduction

The emerging advantages of wireless network inspire other technical fields to solve their own bottlenecks through the network approach [1]. In our researches, we devote to put forward a network-aware solution for a bottleneck of modern navigation technology, which restricts it from stage of a higher level [1–3]. That is, the level of navigation efficiency is closely related to self-contained degree of navigation system, on one hand, the upgrade of its integrity will increase the burdens on economic investment and physical load, on the other hand, if we simplify the complexity of navigation equipment to alleviate the above burdens, its navigation capacity will be degraded accordingly. In previous works [4–6], we proposed a novel network architecture, namely Navigation Carrier Ad Hoc Networks

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(NC-NET), to handle the navigation-related issues, in terms of cooperative navigation, localization, target tracking, and multimedia data exchange, through a network approach. The proposed NC-NET, which is essentially ad hoc network between navigation carriers (NCs), is surveyed as a new network family. Hereinto, navigation carrier is defined as the carrier that has the demands of localization and/or navigation, such as aircraft, car, ship, submarine, buoyage system, and satellite or pseudo satellite. In [4–6], we finished partial protocols and mechanisms as follows: (i) the protocol framework, and the models in physical layer [4,5]; (ii) a diffserv-based dynamic cooperative MAC protocol, i.e., DDC-MAC [4]; (iii) a distributed multi-weight data-gathering and aggregation protocol for cluster topology, i.e., DMDG [5]; and (iv) a network-based localization mechanism [6]. As part of a series of research work, the main objective of this paper is to develop a QoS-aware routing protocol with full account of the unique challenges in NC-NET.

In previous literature, the QoS-aware routing problem (QRP) has been investigated extensively [7–12]. However, in QRP of NC-NET, we should integrate into account several unique challenges that never handled in existing work, including: (i) coexistence of multiple traffic services with heterogeneous QoS requests; (ii) coexistence of short-range and long-range traffic requests; and (iii) harsh routing environment, i.e., sparse network density, long-range transmission, and high-dynamic topology.

In network layer, the kernel issue of challenge (i) is to determine a feasible route-strategy that can satisfy all the quality-of-service (QoS) requirements of multiple applications in the given network architecture and resources. Thus in previous literature, this challenge is explored, independent or cross-linked, through the perspectives as follows: traffic-class-based approach, network-condition-based approach, and routing-algorithm-based approach. For the first approach, the objective is to achieve desired QoS routing performance by particular priority strategy. Hereinto, in [7], the heterogeneous services are assigned to different priorities according to the QoS metrics in terms of importance, delay-sensitivity, and packet-loss sensitivity. In [9], the services are classified based on communicative features in terms of time-driven, event-driven, fusion-driven, data query, and stream query services. In [10], the services are classified directly according to the service types in terms of video, voice, and data. Then, these services are offered with different service qualities according to their priorities. The second approach is designed based on the QoS metrics related to network conditions, e.g., link-lifetime [11], bandwidth-power [12], energy efficiency [13]. Finally, the third approach aims to achieve the desired QoS metrics by means of routing algorithm, typical solutions include cooperative strategy [14], ant-colony optimization [7], genetic algorithm, simulated annealing, tabu search [15], and other heuristic algorithms [16].

Challenge (ii) is one of the key issues in multi-hop routing environment, which can decompose into two sub-puzzles: (1) How to maximize the advantages of the both sides: i.e., the high-efficiency cause by short-range transmission, and large-scale action area due to long-range transmission. (2) How to minimize the contradiction of the both sides, i.e., guarantee QoS-aware long-range transmission with the contention from frequent short-range exchange. In [17,18], cluster-based routing is exploited as one of the most effective solutions for these sub-puzzles, in which the above traffic requests are dipartite according to the cluster structure. However, its disadvantages are that the cluster heads (CH) may become local "Hotspots" of the network, and lead to congestion and contention; moreover, the long-range transmission between CHs maybe not the optimal routes. Thus, several distributed approaches are developed to avoid this bottleneck, e.g., grid-based routing [19], cooperative transmission [20–23], and heuristic routing [16,24]. In grid-based routing strategies [19], the network field is divided into disjoint grids, logically or geographically; thus the routing can be proceed based on these grids, which can avoid congestion effectively and guarantee QoS metrics in terms of end-to-end and bandwidth reservation. Cooperative approach is another distributed routing strategy, which can solve this "Hotspots" problem and enhance the routing efficiency by improving the reuse level of radio resources [20,21]; moreover, the combination of group-based and cooperative approaches can exploit several attractive properties, i.e., virtual multiple-input-multiple-output (V-MIMO) [22], and equivalent multiple reception (MPR) [23]. Besides, Heuristic routing, mainly based on nature inspired and cognitive empirical-based algorithms, can afford QoS-aware routing services by cooperating with credible history information, the related survey please refer to [16,24], and the details will be further analyzed in Section 2.2.

With these comparisons, it is clear that the results on challenge (i), challenge (ii), and their hybrid are extensive; however, in harsh environment that of challenge (iii), the integrated investigates on challenges (i) and (ii) are quite limited. From above analysis, we identify the missing properties in the existing work for QoS provisioning in NC-NET and introduce the design and implementation of a new fading memory cooperative QoS routing (FMCQR) protocol for NC-NET. FMCQR is designed with key features to support the above three challenges. These features include: (i) grid-based 3D geographic distribution, (ii) grid-based cooperative transmission, and (iii) memory-based routing optimization. Although some of these key components have been integrated in previous routing protocols for WMSNs [7–24], FMCQR is the first all-in-one QoS-aware routing protocol proposed for NC-NET that meets the requirements of the above three challenges. The key contributions of this work and highlights of FMCQR are listed as follows:

(i) We propose a solid analytical derivation for a 3D geographic grid, i.e., TGG, which can act as a space basic for virtual addressing and cooperative routing.
(ii) A novel cooperative strategy, namely Controlled Virtual Node (CVN), is explored to aggregate the routing resources within a TGG border; thus, the high-dynamic topology composed by SISO nodes can be converted into a static or low-dynamic topology composed by CVN.
(iii) A bran-new routing approach is presented based on TGG space and CVN graph. The objective of this approach is to provide QoS-aware service for

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