

Information about DUPLICATION

Articles [KK, K-PhD] by Karp and Kung, presenting GPSR routing protocol with guaranteed delivery, is a DUPLICATION of our protocol GFG published one year before in [BMSU].

[KK, K-PhD] cites [BMSU], but misrepresents the contribution in [BMSU], and then describes very same algorithms.

[KK] Brad Karp and H.T. Kung, GPSR: Greedy perimeter stateless routing for wireless networks, Proc. ACM MOBICOM, Aug. 2000, 243-254.

[K-PhD] Brad Karp, Geographic routing for wireless networks, Pd.D. Dissertation, Harvard University, October 2000.

Journal version of [KK] or [K-PhD] was not found yet.

[BMSU] Prosenjit Bose, Pat Morin, Ivan Stojmenovic and Jorge Urrutia, Routing with guaranteed delivery in ad hoc wireless networks, Proc. of 3rd ACM Int. Workshop on Discrete Algorithms and Methods for Mobile Computing and Communications DIAL M99, Seattle, August 20, 1999, 48-55. ACM/Kluwer Wireless Networks, 7, 6, November 2001, 609-616. Available at www.site.uottawa.ca/~ivan.

Karp and Kung [KK] made the following statement about the contribution in [BMSU]:

‘Bose *et al.* [3] independently investigated the graph algorithms for rendering a radio network’s graph planar. They suggest the Gabriel Graph, and analyze the increase in path length over shortest paths when traversing a graph using *only* perimeters. Motivated by the longer-than-optimal paths perimeter traversal alone finds, they suggest combining planar graph traversal with greedy forwarding, and verify that this combination produces path lengths closer to true shortest paths. ***They do not present a routing protocol, do not simulate a network at the packet level, and assume that all nodes are stationary and reachable.***’

Response: This first and main part of the statement is contradictory. After nicely summarizing contribution of [BMSU], the last sentence denies it. [BMSU] has a description, pseudo-code, and three figures to illustrate face routing. It also contains GFG description as follows:

‘Figure 6 shows the results of applying *greedy* until the packet reaches a node *v* such that all of *v*’s neighbours are further from the destination than *v* is. The FACE-2 algorithm was then applied until the packet reached another vertex *u* that was strictly closer to the destination than *v* at which point the *greedy* algorithm was resumed. In this scenario, FACE-2 can be seen as a means of overcoming local minima in the objective function (distance to destination). We refer to this algorithm as GFG.’

The contributions of [KK, K-PhD] are as follows:

- Very nice description of Face routing and GFG, much more readable than description in [BMSU], which contributed to the acceptance of the protocol by the community. This is probably what [KK, K-PhD] mean by stating that [BMSU] ‘do not present a routing protocol’. One cannot deny the existence of a routing protocol just because it is not well presented.

- Considering sparser RNG graph in addition to GG (however, sparser graph increases hop count and thus worsens performance),
- Considering the variant of changing face before crossing instead of changing it after crossing (this variant was considered by our group but the performance was found to be somewhat worse, and only better variant was presented; more precisely, the protocol description in [BMSU] allows for both variants but figure illustration suggests after crossing variant),
- Experimenting with a more realistic medium access layer instead of ideal one used in [BMSU] (this is what [KK, K-PhD] mean by ‘do not simulate a network at the packet level’,
- Experimenting with moving nodes instead of stationary ones. However, [KK, K-PhD] still assume that, despite moving, destination location is accurately known to sender. When the speed of transmission of much higher that speed of movement (which is a usual assumption), this has little impact on performance.

Because of the duplication of our article in highly visible ACM MOBICOM conference, a significant number of researchers (over one hundred) have cited the duplication [KK, K-PhD], and not the origin of the method [BMSU].

[KGKS] Young Jin Kim, Ramesh Govindan, Brad Karp, Scott Shenker, On the Pitfalls of Geographic Face Routing, ACM DIALM-PODC, Sept. 2005.

[FS] Hannes Frey, Ivan Stojmenovic, On Delivery Guarantees of Face and Combined Greedy-Face Routing Algorithms in Ad Hoc and Sensor Networks, The Twelfth **ACM Annual International Conference on Mobile Computing and Networking MOBICOM**, Los Angeles, Sept. 23-29, 2006, 390-401 (acceptance rate <12%).

Summary from [FS]:

In 2005, B. Karp et al [KGKS] claimed that all known face and combined greedy-face routing variants cannot guarantee message delivery in arbitrary undirected planar graphs. In 2006, we [FS] have clarified that this is not the truth in general. We show [FS] that specifically in relative neighborhood and Gabriel graphs recovery from a greedy routing failure is always possible without changing between any adjacent faces. Guaranteed delivery then follows from guaranteed recovery while traversing the very first face, and not from applying a face routing procedure that itself has to guarantee delivery. In arbitrary graphs, however, a proper face selection mechanism is of importance since recovery from a greedy routing failure may require visiting a sequence of faces before greedy routing can be restarted again. A prominent approach is to visit a sequence of faces which are intersected by the line connecting the source and destination node. Whenever encountering an edge which is intersecting with this line, the critical part is to decide if face traversal has to change to the next adjacent one or not. Failures may occur from incorporating face routing procedures that force to change the traversed face at each intersection. Recently observed routing failures which were produced by the GPSR protocol [KK] in arbitrary planar graphs result from incorporating such a face routing variant. They cannot be constructed by the well known GFG algorithm [BMSU] which does not force changing the face anytime but instead selects the face that intersects with the remaining portion of the line segment from the current intersection towards the destination node. As a consequence, face traversal sometimes remains on the same face. Besides methods which visit the faces intersected by the source destination line, we [FS] discuss face routing variants which are volatile in the sense that they simply restart face routing whenever the next face has to be explored. We give the first complete and formal proofs that several proposed face routing, and combined

greedy-face routing schemes do guarantee delivery in specific graph classes or even any arbitrary planar graphs. We [FS] also discuss the reasons why other methods may fail to deliver a message and end up in a loop.

Therefore, it appears that authors [KK] of GPSR misunderstood the functioning of GFG protocol [BMSU] while duplicating and made a mistake in their coding which was luckily not discovered until experimenting with arbitrary planar graphs ... while the code for GFG presented in [BMSU] is correct!

Duplication has been confirmed by a number of independent researchers (in addition, a number of articles claims ‘independent’ discovery of the same algorithm). Partial list follows.

L. Barriere, P Fraigniaud, L. Narayanan, and J. Opatrny, Robust position-based routing in wireless ad hoc networks with irregular transmission ranges, *Wireless Communications and Mobile Computing*, 3, 2, 2003, 141-153; Proc. of 5th ACM Int. Workshop on Discrete Algorithms and Methods for Mobile Computing and Communications DIAL M01, 2001, 19-27.

‘To overcome the failure of all these routing strategies, Bose *et al.* [1] described a routing algorithm that guarantees delivery of messages in MANETs. (The transformation of this algorithm into a protocol named Greedy Perimeter Stateless Routing (GPSR) was later presented by Karp and Kung [2].)’

X.Y. Li, G. Calinescu, P.J. Wan and Y. Wang, Localized Delaunay triangulation with application in ad hoc wireless networks, *IEEE Transactions on Parallel and Distributed Systems*, 14,10,Oct. 2003, 1035-1047.

‘Bose et al. [BMSU] proposed to use the Gabriel graph as the underlying structure for the FACE routing method. Subsequently, Karp et al [KK] discussed, in detail, the medium access layer and conducted experiments with moving nodes for the face routing method.’

X.Y. Li, K. Moaveninejad, W.Z. Song, Robust position-based routing for wireless ad hoc networks, *WWAN at IEEE ICDCS*, Tokyo, March 2004.

‘Bose et al [BMSU] proposed to use the Gabriel graph as underlying structure for the FACE routing method. Subsequently, Karp et al [KK] discussed in detail of medium access layer and conducted experiments with moving nodes for Face routing method.’

D. Niculescu and B. Nath, Trajectory based forwarding and its applications, *Proc. ACM MOBICOM*, San Diego, CA, Sept. 2003, 260-272.

‘The most relevant work related to avoiding obstacles in routing is the FACE algorithm [BMSU] (see also [KK]), which is stateless and localized.’

F. Kuhn, R. Wattenhofer, A. Zollinger, Ad-hoc networks beyond unit disk graphs, *ACM DIALM-POMC*, San Diego, Sept. 2003, 69-78.

‘The first algorithms with guaranteed delivery were [BMSU, KSU] followed by a slightly changed approach in [KK]’

R. Wattenhofer, *Mobile Computing*, Summer 2003, Chapter 7: Geometric Routing,

<http://dcg.ethz.ch/lectures/ss03/mobicomp/lecture/7/Chapter7GeometricRouting4Slides.pdf>

‘GPSR is a new name for GFG’.

L. Zou, M. Lu, Z. Xiong, PAGER: A distributed algorithm for the dead-end problem of location-based routing in sensor networks, submitted to ICCCN, 2004.

‘The Greedy-Face-Greedy (GFG)/Greedy Perimeter Stateless Routing (GPSR) algorithm [BMSU, KK] is currently the most accepted stateless recover mode algorithm in ad hoc/sensor networks in existing literature. GFG/GPSR elegantly handles the dead-end problem by routing a message along faces.’

K. Seada, A. Helmy, An overview of geographic protocols in ad hoc and sensor networks, 3rd ACS/IEEE Int. Conf. on Computer Systems and Applications, Cairo, Egypt, Jan. 3-6, 2005.

D. Son, A. Helmy, B. Krishnamachari, "The Effect of Mobility-induced Location Errors on Geographic Routing in Mobile Ad Hoc and Sensor Networks: Analysis and Improvement using Mobility Prediction", *IEEE Transactions on Mobile Computing, Special Issue on Mobile Sensor Networks*, 3,3, July 2004, 233-245.

‘geographic routing in [KK], or the algorithm described earlier in [BMSU], is a location-based routing protocol for wireless networks, and consists of two packet forwarding modes: greedy packet forwarding and perimeter forwarding.’ Details are given then in one paragraph, which apparently applies to both [KK] and [BMSU].

K. Seada, A. Helmy, An overview of geographic protocols in ad hoc and sensor networks, 3rd ACS/IEEE Int. Conf. on Computer Systems and Applications, Cairo, Egypt, Jan. 3-6, 2005.

‘Bose *et al.* [BMSU] and GPSR [KK] present the common form of greedy forwarding in ad hoc networks. Packets contain the position of the destination and nodes need only local information about their position and their immediate neighbors’ positions to forward the packets. As shown in Figure 2, each wireless node forwards the packet to the neighbor closest to the destination among its neighbors (within radio range) that are closer to the destination.’

‘Bose *et al.* [BMSU] presented algorithms and proofs for extracting planar graphs from unit graphs and for face routing in the planar graphs to guarantee delivery. Due to the inefficient paths resulting from face routing, they proposed combining face routing with greedy forwarding to improve the path length. Face routing is used when greedy forwarding fails until a node closer to the destination is reached, then greedy forwarding could be resumed again. This way the algorithm will remain loop-free.’

‘GPSR [KK] is a geographic routing protocol for wireless networks that combines greedy forwarding and face routing (perimeter routing). This work provides packet-level simulations using 802.11 wireless MAC layer and comparisons with an ad hoc routing protocol, DSR.’

Karim Seada, Ahmed Helmy, Ramesh Govindan, Modeling and Analyzing the Correctness of Geographic Face Routing under Realistic Conditions, IPSN journal draft.

‘Bose *et al.* [BMSU] discuss algorithms for extracting planar graphs from unit graphs and for face routing in the planar graphs to guarantee delivery. Due to the inefficient paths resulting from face routing, they propose combining face routing with greedy forwarding to improve the path length.’

K. Seada, A. Helmy, Geographic services for wireless networks, in: Handbook of Algorithms for Wireless Networking and Mobile Computing (A. Boukerche, ed.), Chapman & Hall/CRC, 2006, 343-364.

‘Bose et al.[BMSU] and GPSR [KK] present the common form of greedy forwarding in ad hoc networks.’

D. Malkhi, Locality aware network solutions (a survey), Hebrew University, Israel, Leibniz Center, TR 2004-6, May 2004.

‘Both Bose et al. [BMSU] (GFG) and Karp and Kung [KK] (GPSR) propose an algorithm that combines greedy routing with face routing.’

Marc Heissenbuettel, Torsten Braun, David Joerg, Thomas Huber, A Framework for Routing in Large Ad-hoc Networks with Irregular Topologies, *Fourth Annual Mediterranean Ad Hoc Networking Workshop, Porquerolles, 21-24 June 05; AHSWN, to appear.*

‘Perhaps the most cited position based routing protocols is GPSR [KK] which is however only an extension of the earlier published GFG [BMSU] with MAC-layer enhancements. Thus, in this paper we refer to these algorithms together as GFG/GPSR.’

Thomas Fevens, Alaa Eddien Abdallah, and Badr Naciri Bennani, Randomized AB-Face-AB Routing Algorithms in Mobile Ad Hoc Networks, V.R. Sirotiuk and E. Chavez (Eds.): ADHOC-NOW 2005, LNCS 3738, pp. 43–56, 2005.

‘This algorithm is termed *GFG* (Greedy-Face-Greedy) by [BMSU] and *GPSR* (Greedy Perimeter Stateless Routing) by [KK].’

Stefan Funke, Topological Hole Detection and its Applications, ACM DIALM-PODC, Sept. 2005.

‘One powerful approach to routing within wireless networks is the idea of geographic routing pioneered in GPSR / GFG [BMSU, KK].’

Filipe Araújo, Luís Rodrigues, On the Monitoring Period for Fault-Tolerant Sensor Networks, Lecture Notes in Computer Science, Volume 3747, Oct 2005, Pages 174 – 190.

‘Therefore, we selected the Greedy Perimeter Stateless Routing (GPSR) algorithm [BMSU, KK], because it is localized, and efficient.’

Young-Jin Kim, Ramesh Govindan, Brad Karp, Scott Shenker, **Geographic Routing Made Practical**, In *Proceedings of the USENIX Symposium on Networked Systems Design and Implementation*, Boston, Massachusetts, USA:USENIX, May 2005.

‘We now describe the shared characteristics of the GFG, GPSR, and GOAFR+ algorithms, and hereafter refer to this family of algorithms simply as geographic routing.’

Young Jin Kim, Ramesh Govindan, Brad Karp, Scott Shenker, On the Pitfalls of Geographic Face Routing, ACM DIALM-PODC, Sept. 2005.

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Young-Jin Kim, Ramesh Govindan, Brad Karp, Scott Shenker, **Geographic Routing Made Practical**, In *Proceedings of the USENIX Symposium on Networked Systems Design and Implementation*, Boston, Massachusetts, USA:USENIX, May 2005.

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