FAST FACE ROUTING PROTOCOL FOR SHORTER DELAY GUARANTEED DELIVERY IN MANET

Tomokazu Ezaki and Hiroaki Higaki
Department of Robotics and Mechatronics
Tokyo Denki University
+81-3-5284-5606
Senju-Asahi 5, Adachi, Tokyo 120–8551 Japan
email: {ezaki, hig}@higlab.net

ABSTRACT
FACE-2 is a location-based ad-hoc routing protocol with guaranteed delivery of data messages. Each intermediate wireless node requires not global topology information of an ad-hoc network but location information of only their neighbor and the destination wireless nodes to forward data messages. However, since the data messages tend to detour, their end-to-end transmission delay gets longer. In order for shorter delay transmissions, this paper proposes Fast-FACE in which copies of data messages are transmitted along edges of faces in both directions. It is expected for Fast-FACE to achieve shorter and stable end-to-end transmission delay than FACE-2. It also guarantees that all the copies of data messages not reaching the destination wireless node surely discarded. The preliminary simulation experiments show that copies of data messages cause longer transmission delay due to contentions. This paper also discusses improved implementation to solve this problem.

KEY WORDS
Ad-Hoc Networks, Location-Based Routing, FACE, GPSR, End-to-End Transmission Delay.

1 Introduction
Recently, due to advances of mobile computers with wireless communication devices, mobile wireless networks become widely available. In addition, research and development of wireless sensor networks for continuously achieving sensor data by numerous numbers of sensor wireless nodes with wireless communication also become active [3]. Since power sources of these mobile wireless nodes are batteries with limited capacity, reduction of power consumption for wireless communication is critical for longer lifetime of the wireless nodes. Thus, wireless multihop transmissions are usually applied in mobile ad-hoc networks (MANETs), wireless sensor networks and mesh networks and various routing protocols for data message transmissions have been proposed [10]. Especially for lower power consumption communication by reduction of transmissions of additional control messages, location-based ad-hoc routing protocols such as FACE [2], GPSR [7], GEDIR [9], COMPASS [8] have been proposed in which it is assumed that all wireless nodes have GPS receivers and no flooding of control messages are applied.

In these protocols, different from such protocols as AODV [11] and DSR [4] which detect a wireless multihop transmission route from a source wireless node to a destination one for a sequence of data messages, a transmission route is determined for each data message dynamically. On receipt of a data message forwarded from a previous-hop neighbor wireless node, each intermediate wireless node dynamically determines its next-hop wireless node based on the most recently achieved location information of itself, its neighbor wireless nodes and the source and the destination wireless nodes. Hence, each wireless node periodically broadcasts a control message with its current location information achieved by using its GPS receiver. Location information of the source and the destination wireless nodes are usually piggybacked to data messages or achieved by location advertisement or acquisition protocols.

Since most of the location-based ad-hoc routing protocols are greedy ones based on the partial location information with low communication overhead. Hence, data messages sometimes do not reach their destination wireless nodes, which is called a deadend. However, though the next-hop wireless node is determined in each intermediate wireless node without global location information, FACE realizes guaranteed delivery of data messages, i.e., FACE is a deadend-free location-based routing protocol. For the guaranteed delivery based only on localized location information, the resulting wireless multihop transmission routes tend to be longer than those detected by other routing protocols. The goal of this paper is to propose an extension of FACE which realizes guaranteed delivery with shorter end-to-end transmission delay. The perimeter mode in GPSR is fundamentally same as FACE and the proposed extension is also applied to GPSR.

2 Related Works
2.1 Location-Based Ad-Hoc Routing Protocols
In a wireless multihop network, data messages are transmitted along a wireless multihop transmission route \( R := \langle N_0 \ldots N_n \rangle \) which is a sequence of intermediate wireless nodes \( N_i \) from a source wireless node \( N^*(=N_0) \) to a des-
tination wireless node $N^d_i (= N_1)$. Here, $N_{i+1}$ should be in a wireless transmission range of $N_i$. Flooding-based on-demand ad-hoc routing protocols such as AODV and DSR require flooding of a route request control message $Rreq$ for detection of a wireless transmission route without location information of wireless nodes. However, overall flooding especially in large-scale ad-hoc networks requires high communication overhead and it is difficult to determine proper TTL of flooding for reduction of communication overhead. In addition, since the detected multihop transmission route is not stable for a sequence of data messages, required communication overhead for localized repair of the route or for re-detection of the route should be reasonably lower. Thus, for applying the flooding-based routing protocols, speed and frequency of mobility and possibility of failures in wireless nodes should be strictly restricted.

On the other hand, in location-based ad-hoc routing protocols such as FACE, GPRS, GEDIR and COMPASS, each intermediate wireless node with a GPS receiver dynamically determines its next-hop wireless node. Hence, these protocols are highly adaptive to high speed and high frequent mobility in ad-hoc networks. In these protocols, on receipt of a data message from a previous-hop neighbor wireless node, an intermediate wireless node determines its next-hop wireless node based not on the global location information of the ad-hoc network but on the localized location information, i.e., location information of itself, its neighbor wireless nodes and the source and the destination wireless nodes, and forwards the data message to it. In GEDIR, COMPASS and the greedy mode in GPR, there exists a deadend where an intermediate wireless node cannot determine its next-hop wireless node even though there is at least one wireless multihop transmission route from the source to the destination since it determines its next-hop wireless node by applying a greedy algorithm based on the localized location information. However, in FACE and the perimeter mode in GPRS, though each intermediate wireless node also determines its next-hop wireless node based on the localized location information, guaranteed delivery of data message is realized. That is, if there exists at least one wireless transmission route from the source to the destination, data messages are surely transmitted without deadends.

### 2.2 FACE Routing Protocols

FACE is one of the location-based ad-hoc routing protocols. Though an intermediate wireless node determines its next-hop node based only on the localized location information, i.e., location information of its neighbor wireless nodes, data messages surely reach their destination wireless nodes. That is, deadend-free guaranteed delivery of data messages is realized. In addition, it is required for wireless nodes to have message buffers only to store data messages waiting for their transmission due to contentions. This section provides overview of FACE.

As shown in Figure 1, a wireless multihop network is modeled by a graph whose vertices and edges correspond to wireless nodes $N_i$ and wireless communication links $\langle N_i, N_j \rangle$, respectively. Here, there exists a bidirectional wireless communication link $\langle N_i, N_j \rangle$ between neighbor wireless nodes $N_i$ and $N_j$ if the distance $|N_iN_j|$ between them is less than or equal to the wireless transmission range $r$. This is called a disk model [2]. This graph is not always a planer graph; that is, there are some intersections of two edges not corresponding to a vertex. For guaranteed delivery of data messages, a planer spanning subgraph such as the Gabriel subgraph [5] and the relative neighborhood subgraph [7] are induced by removal of some edges. The original FACE adopts the Gabriel subgraph.

**[Gabriel subgraph for FACE]**

Let $\mathcal{N}$ be a set of vertices $\{N_1, \ldots, N_m\}$ corresponding to wireless nodes. A Gabriel subgraph is a planer graph whose edges $N_iN_j$ corresponding to wireless communication links $\langle N_i, N_j \rangle$ satisfy the following conditions:

1) $|N_iN_j| \leq r$

2) $\forall N' \in \mathcal{N}, N'$ is out of a circle whose diameter is a line segment $N_iN_j$.

For a wireless multihop network in Figure 1, a Gabriel subgraph in Figure 2 is induced.

![Figure 1. Wireless Multihop Network.](image1.png)

Figure 1. Wireless Multihop Network.

![Figure 2. Gabriel Subgraph for FACE.](image2.png)

Figure 2. Gabriel Subgraph for FACE.

Since the Gabriel subgraph is a planer graph, the plane is partitioned into multiple faces. Adjacent faces share edges and their vertices. If there exists a wireless multihop transmission route from a source wireless node
$N^s$ to a destination one $N^d$, all the faces intersecting with a line segment $N^sN^d$ are simply connected polygons and have at least two adjacent faces intersecting with $N^sN^d$ if they do not contain $N^s$ and $N^d$ as their vertices. For example in Figure 2, a line segment $N^sN^d$ intersects with three faces $F_1$, $F_2$ and $F_3$ and these faces are simply connected polygons. $F_2$ does not contain $N^s$ and $N^d$ and has two adjacent faces $F_1$ and $F_3$ intersecting with $N^sN^d$.

Since the length of all the edges in each face is less than or equal to $r$, there are corresponding wireless communication links through which wireless nodes corresponding to vertices of the edges transmit data messages. Thus, it is possible for data messages to be transmitted along edges of a face. In FACE, data messages are only transmitted along edges of faces intersecting with a line segment $N^sN^d$, which realizes guaranteed delivery of data messages. In the following FACE-1, a data message $m$ traverses around each face and the edge which intersects with $N^sN^d$ and the intersection is the nearest to $N^d$. Then, $m$ is transmitted one of the vertices of the edge and the transmission in the adjacent face is initiated, which is continued until $m$ reaches $N^d$. Figure 3 shows an example for transmission of $m$ from $N^s$ to $N^d$.

**[FACE-1 Protocol]**

$p \leftarrow N^s$

repeat

let $F$ be the FACE of $G$ with $p$ on its boundary that intersects line segment $(p, N^d)$

foreach edge $(N, N')$ of $F$

if $(N, N')$ intersects $(p, N^d)$ in a point $p'$ and $\text{dist}(p', N^d) < \text{dist}(p, N^d)$

$p \leftarrow p'$

end if

end for

Traverse $F$ until reaching the edge $(N, N')$ containing $p$

until $p = N^d$

Figure 3. FACE-1 Protocol.

An intermediate wireless node $N_i$ determines its next-hop by using only location information of its neighbor wireless nodes for transmission of a data message $m$ along edges of a face. Suppose $N_i$ receives $m$ from one of its neighbor wireless node $N_{i-1}$. $N_i$ verifies whether each edge $N_iN$ for each neighbor wireless node $N$ is included in the Gabriel subgraph. This is realized by examining whether there are wireless nodes in a circle whose diameter is $N_iN$. Since the circle is included in a wireless range of $N_i$, the examination is possible only with the location information of neighbor wireless nodes of $N_i$. Then, $N_i$ selects $N$ as its next-hop node where an angle $\angle N_{i-1}N_iN$ is the smallest in a counter-clockwise direction if $m$ is transmitted along edges in the face in a clockwise direction. On the other hand, if $m$ is transmitted along edges in the face in a counter-clockwise direction, $N_i$ selects $N$ as its next-hop node where an angle $\angle N_{i-1}N_iN$ is the smallest in a clockwise direction. Therefore, $N_i$ forwards $m$ to $N$ which is selected only based on location information of its neighbor wireless nodes.

![Figure 4. Next-Hop Selection in FACE.](image)

In FACE-1, $m$ is transmitted through all the edges of the faces intersecting with a line segment $N^sN^d$ to forward $m$ to the adjacent faces nearer to $N^d$. Thus, $m$ is traversed along a longer wireless multihop route and end-to-end transmission delay becomes longer. In order to achieve shorter delay transmission of data messages, FACE-2 only transmits $m$ along edges in each face until $m$ reaches one of vertices of an edge intersecting $N^sN^d$. As shown in Figure 5, $m$ is only transmitted along part of the edges of each face and shorter transmission delay is expected. Here, transmission direction in each face is arbitrary and a method in which transmission direction is changed each time $m$ is forwarded to the next face has been proposed.

**[FACE-2 Protocol]**

$p \leftarrow N^s$

repeat

let $F$ be the FACE of $G$ with $p$ on its boundary that intersects $(p, N^d)$

traverse $F$ until reaching an edge $(N, N')$ that intersects $(p, N^d)$ at some point $p' \neq p$

$p \leftarrow p'$

until $p = N^d$

2.3 Requirement for Shorter Delay

In FACE and the perimeter mode in GPSR, guaranteed delivery of data messages is realized by transmitting them
along edges of each face intersecting with a line segment \(N^s N^d\). Since the faces are configured by the Gabriel subgraph in FACE and by the relative neighborhood subgraph in GPSR, edges corresponding to relative longer wireless communication links are removed from the original ad-hoc network. Hence, hop counts of wireless transmission routes are increased and end-to-end transmission delay of data messages becomes longer. In GPSR, combination of the greedy and the perimeter modes mitigates this longer end-to-end delay problem. In Skip FACE [6], data messages are transmitted through not all of the intermediate wireless nodes corresponding to vertices of faces. Here, based on location information of neighbor wireless nodes, some of them are skipped for shorter end-to-end transmission delay.

In FACE-2, different from FACE-1, since data messages are not transmitted along all the edges of each face, end-to-end transmission delay is reduced. However, it depends on the transmission direction of a data message \(m\) which the source wireless node \(N^s\) selects. As shown in Figure 6, \(m\) reaches \(N^d\) through the 7-hop transmission route if \(N^s\) selects a clockwise direction transmission in face \(F_1\). On the other hand, if \(m\) is transmitted in a counterclockwise direction in \(F_1\), \(m\) reaches \(N^d\) after traversing the 23-hop transmission route. It is impossible for \(N^s\) to select the shorter transmission route for \(m\) based only on the localized location information of its neighbor wireless nodes. In addition, as shown in Figure 7, the resulting hop counts are 7 and 34 with clockwise and counterclockwise directions in \(F_1\) respectively. This larger difference is caused by the open face \(F_4\). A routing method to transmit data messages along edges of an open face in direction with smaller hop counts to the next face is proposed for the perimeter mode in GPSR [1]. As shown in Figure 8, the intermediate wireless node that begins transmission of \(m\) along the open face \(F_4\) determines to transmit \(m\) in a counter-clockwise direction for shorter delay to reach the destination wireless node \(N^d\). In order to realize this selection of the transmission direction, all the wireless nodes corresponding to the vertices of the open face are required to share their up-to-date location information among them by continuously exchanging control messages with adjacent wireless nodes through wireless communication links corresponding to the edges of the open face. This requires high communication overhead since the exchanges of the control messages are required independently of transmission requests of data messages. In addition, though the original location-based ad-hoc routing protocols such as FACE and GPSR are stateless and each wireless node is required to keep only localized location information, this extension of GPSR requires each wireless node to manage the topology information of the open face.

Figure 6. Transmission Routes in FACE-2 without Opne Face.

Figure 7. Transmission Routes in FACE-2 with Opne Face.

\(^{a1}\) \(N^d\) is one of the vertices of \(F_4\) in this case.
3 Fast-FACE Protocol

3.1 Introduction of Copies of Data Messages

As mentioned in the previous section, end-to-end transmission delay of data messages in FACE-2 is long and unstable. For improvement, this paper proposes an extension Fast-FACE of the original FACE-2 in which copies of data messages are transmitted along edges of each face in both clockwise and counter-clockwise directions. As shown in Figure 9, copies of a data message \( m \) are transmitted along edges of a face \( F \) in both clockwise and counter-clockwise directions. Hence, as in Figure 10, one of the copies of \( m \) reaches an intermediate wireless node corresponding to a vertex of an edge shared by both \( F \) and the next face and intersecting with a line segment \( N_s N_d \) through a shorter transmission route before the other.† Then, the intermediate wireless node also initiates transmissions of copies of \( m \) along edges of the next face in both clockwise and counter-clockwise directions. As a result, a copy of \( m \) through the shorter transmission routes in each face first reaches \( N_d \) earlier. Though Fast-FACE requires additional communication overhead for transmissions of copies of \( m \), the shortest end-to-end transmission delay of \( m \) is achieved under the restriction that \( m \) is only transmitted along edges of the Gabriel subgraph for guaranteed delivery of \( m \).

3.2 Avoidance of Redundant Transmissions

In Fast-FACE, one of the copies of \( m \) transmitted along edges of a face \( F \) reaches an intermediate wireless node corresponding to a vertex of an edge shared by \( F \) and the next face and intersecting with a line segment \( N_s N_d \). Then, transmissions of copies of \( m \) in both directions along edges of the next face are initiated. The other copy of \( m \) transmitted along edges of \( F \) also reaches another intermediate wireless node corresponding to a vertex of an edge shared by \( F \) and the next face. If the intermediate wireless node also initiates transmissions of copies of \( m \) in the next face, such redundant transmissions of copies of \( m \) increase communication overhead as in Figure 11. Transmission power in intermediate wireless nodes are wasted and contentions among neighbor wireless nodes result in longer end-to-end transmission delay of data messages. For avoidance of the redundant transmissions, an intermediate wireless node initiating transmissions of copies of \( m \) in the next face keeps the copy of \( m \) and suspends the transmission of the other copy of \( m \) in \( F \) on its receipt [12]. However, this method requires message buffers to keep copies of data messages and it is difficult for the data messages to be removed from the message buffer in cases that the copies of \( m \) do not reach intermediate wireless nodes corresponding to the vertices sharing the same edge intersecting with \( N_s N_d \) since the face is a concave polygon and more than two edges intersect with a line segment \( N_s N_d \) as in Figure 12.

In order to solve this problem, a data message \( m \) is continuously transmitted along edges of a face \( F \) even after it reaches an intermediate wireless node shared by \( F \) and the next face intersecting with \( N_s N_d \). By this continuous transmission of the copy of \( m \), both of the copies of \( m \) being transmitted in both directions in \( F \) reach a certain wireless node in \( F \) simultaneously even if \( F \) is a concave polygon since the copies of \( m \) are never simultaneously transmitted along the same wireless communication link in different directions in half-duplex wireless LAN protocols such as IEEE 802.11 and sensor network protocols such as Zigbee (IEEE 802.15.4). The copies of \( m \) transmitted in different directions in \( F \) are surely discarded by this wireless node. Thus, redundant transmissions of

†Due to contentions in each intermediate wireless node, a copy of \( m \) through a shorter transmission route does not always reach the wireless node before the other. However, a copy of \( m \) with shorter transmission delay surely reach the wireless node earlier.
Figure 11. Redundant Transmissions of Copies of Data Messages.

Figure 12. Impossible Removal of Buffered Data Messages in Concave Face.

copies of data messages are avoided and the problem for removal of buffered copies of data messages is solved.

Figure 13. Continuous Transmission of Copy of Data Message in Fast-FACE.

3.3 Implementation

In general, a wireless node $N$ with $n$ neighbor wireless nodes $N_i$ ($0 \leq i < n$) connected by wireless communication links corresponding to edges of the Gabriel subgraph is a vertex of less than or equal to $n$ faces. Along edges of each face, copies of data messages transmitted in both clockwise and counter-clockwise directions reach $N$. Thus, for correspondence between copies of data messages transmitted along edges in the same face in different directions, some additional transmission information should be piggybacked to the copies of data messages. A copy of a data message through $N$ is transmitted along edges of a face containing $N$, $N$ and $N_{(i+1) \mod n}$ in a counter-clockwise direction or a face containing $N$, $N$ and $N_{(i-1) \mod n}$ in a clockwise direction. However, since $N$ has only location information of its neighbor wireless nodes, it is impossible for $N$ to recognize the topology of the faces. Thus, it is impossible for such global information as face IDs to be piggybacked to data messages to mitigate redundant transmissions of copies of data messages.

In the original FACE-2, a transmission direction information $direction$, i.e., clockwise or counter-clockwise, is required to be piggybacked to a data message. Thus, for correspondence between copies of a data message $m$ transmitted along edges of the same face in different directions in Fast-FACE, a 4-tuple $\langle N, N, N, direction \rangle$ where $N$ and $N$ are the previous- and the next-hop wireless node of $N$ respectively, is piggybacked to $m$ when $m$ is temporarily buffered for waiting for transmission in an intermediate wireless node $N$. Before its transmission, if $N$ receives a copy of data message $m$ to which a 4-tuple $\langle N, N, N, direction \rangle$ where $direction \neq direction$ is piggybacked, $N$ discards both the received and buffered copies of $m$ as shown in Figure 14. On the other hand, if there are no corresponding copies of a received data message $m$ in the communication buffer in an intermediate wireless node $N$, $N$ forwards $m$ to its next-hop wireless node.

Even if a face $F$ is a concave polygon as shown in Figure 15, no redundant copies of data messages are transmitted in Fast-FACE. Same as the original FACE-2, each time a copy of a data message $m$ reaches a wireless node corresponding to a vertex of an edge intersecting with the line segment $N_s N_d$, copies of $m$ are transmitted in the next face. Different from the cases of convex faces, multiple wireless nodes in $F$ may forward copies of $m$ to its next face. However, corresponding copies of $m$ surely meet at a certain wireless node in $F$ and are discarded by using the 4-tuples piggybacked to the copies of $m$.

Therefore, Fast-FACE realizes shorter delay guaranteed delivery of data messages without redundant transmissions and continuous buffering of data messages.
4 Evaluation

This section evaluates the performance of Fast-FACE by comparison with the original FACE-2. In a 1,000m × 1,000m simulation field, 300–500 wireless nodes with a 100m wireless transmission range are randomly distributed according to the unique distribution. These wireless nodes are stable and a source and a destination wireless nodes are also selected randomly. Length of resulting wireless multihop transmission routes, i.e., hop counts, transmission delay of a data message and numbers of transmitted messages are evaluated.

Figures 16 and 17 show average and standard deviation of hop counts. Though there exists the effect of contentsions among neighbor wireless nodes, a copy of a data message through shorter sequence of edges in each face reaches the next face earlier and data messages are usually transmitted through the shortest transmission route under the restriction on FACE routing based on the Gabriel subgraph. Thus, Fast-FACE achieves averagely 50.0% (45.4–61.4%) shorter transmission routes than FACE-2. In addition, a copy of data message reaching the destination wireless node is transmitted through dynamically determined shorter route in each face in Fast-FACE. However, hop counts in FACE-2 depend only on the selected transmission direction in the source wireless node. Hence, Fast-FACE achieves 45.3% (31.4–59.6%) lower standard deviation in hop counts than FACE-2; that is, hop counts in Fast-FACE is more stable than FACE-2.

Same as hop counts of transmission routes, end-to-end transmission delay is expected to be shorter in Fast-FACE than in the original FACE-2. However, as shown in Figure 18, Fast-FACE requires more than 100% (106.9–172.5%) longer transmission delay than FACE-2. This is due to contentsions among wireless nodes initiating transmissions of copies of a data message in a next face. As shown in Figure 19, an intermediate wireless node N receives a data message m transmitted in a face F and forwarded by a previous-hop wireless node N−. N forwards copies of m to N′+ for transmission in a next face F′ in a clockwise direction, to N′− for transmission in F′ in counter-clockwise direction and to N same as N′ for continuous transmission in F as discussed in 3.2. These three next-hop wireless nodes of N also forward copies of m.

Here, N and N′+, N and N′(= N+) are exposed wireless nodes each other and contentsions among them cause longer transmission delay. In addition, N transmits a copy of m to N′+ two times and it forwards m to N′+ and N++. These transmissions also contend each other and make transmission delay longer. The possible solution for this problem is discussed in the next section.

Finally, Figure 20 shows the number of transmitted messages. In FACE-2, only the original data message is unicasted without any copies. On the other hand, Fast-FACE introduces copies of data messages for shorter end-to-end transmission delay. Thus, 84.6% (78.0–90.3%) more messages are transmitted as expected since copies of data messages are transmitted in both direction in each face.

5 Conclusion

This paper proposes an extension Fast-FACE of FACE-2 to solve the longer transmission delay problem in the original FACE-2 which realizes guaranteed delivery of data messages. Here, same as FACE-2, an intermediate node determines its next-hop node by only the partial location information and copies of a data message are transmitted
along edges of a face in both directions, i.e., clockwise and counter-clockwise directions. Thus, one of the copies of the data message through the shortest route under the restriction that data messages are only transmitted through the edges in the Gabriel subgraph reaches the destination wireless node. Fast-FACE mitigates redundant transmissions of copies of data messages and additional communication buffers to synchronize the copies in a face transmitted in different directions. The results of simulation experiments show that shorter transmission routes are achieved in Fast-FACE than FACE-2; however, end-to-end transmission delay is longer due to contentions around the wireless node shared by adjacent faces and in which transmissions of copies of data messages in the next face are initiated. For avoidance of additional delay caused by contentions among transmissions of copies of data messages, the authors examine another implementation of Fast-FACE where copies of data messages are not unicasted but broadcasted. Here, multiple transmission information, i.e., the 4-tuples discussed in this paper, are combined and piggybacked to the broadcasted data message. By this implementation, end-to-end transmission delay is also improved and shorter delay data message transmission is expected to be realized.

References