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(71) Applicant: **NEC EUROPE LTD.** [DE/DE]; Kurfürsten-Anlage 36, 69115 Heidelberg (DE).

(72) Inventors: **BOBAN, Mate**; Max-Reger-Strasse 11, 69121 Heidelberg (DE). **GOLEVA, Maria**; Friedhofstrasse 36, Bremen Bremen (DE).

(74) Agent: **ULLRICH & NAUMANN**; Schneidmühlstraße 21, 69115 Heidelberg (DE).

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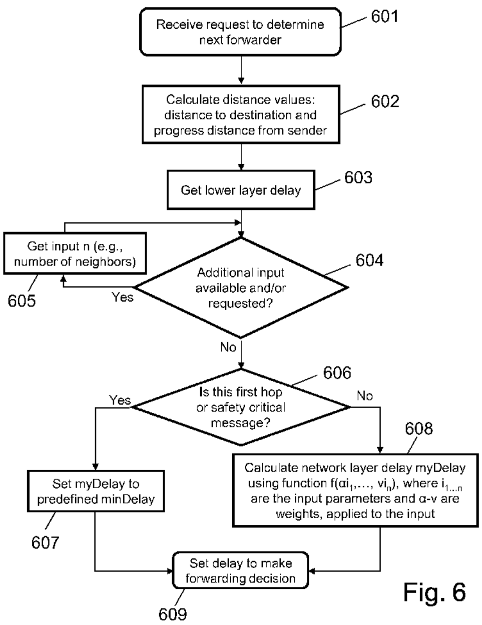

Fig. 6

(57) Abstract: A method for performing contention-based forwarding in a wireless ad hoc network, in particular vehicular ad hoc network, wherein a selection of one or more appropriate forwarder nodes is performed by introducing forwarding delays that discriminate between potential forwarder nodes and that are calculated by applying a forwarding algorithm, is characterized in collecting delay information about delays induced by layers below said forwarding algorithm, wherein said forwarding algorithm takes into consideration said collected delay information for calculating adjusted forwarding delays. Furthermore, a corresponding network node for deployment in a wireless ad hoc network is disclosed.

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METHOD FOR PERFORMING DELAY-AWARE FORWARDING IN A WIRELESS AD HOC NETWORK

The present invention relates to a method for performing forwarding in a wireless ad hoc network, in particular vehicular ad hoc network, by means of a forwarding algorithm.

Furthermore, the present invention relates to a network node for deployment in a wireless ad hoc network, said network node being configured to execute a forwarding algorithm that selects of one or more appropriate forwarder nodes either explicitly or by introducing forwarding delays that discriminate between potential forwarder nodes.

Today, wireless ad hoc networks are employed in various implementations. In particular in the field of Intelligent Transportation Systems vehicular ad hoc network, briefly denoted VANETs, are experiencing extensive attention.

Intelligent Transportation Systems are envisioned to make the travel safer, more efficient, and pleasurable. Vehicle-to-Vehicle (V2V) communication is at the core of ITS systems enabling safety and non-safety applications (for reference, see H. Hartenstein, K. P. Laberteaux: “A tutorial survey on vehicular ad hoc networks“, Communications Magazine 2008, IEEE, 46(6), 164-171).

V2V relies on ad-hoc communication between vehicles to ensure safety-critical data is distributed reliably to intended receivers. In case those receivers are not directly reachable, multi-hop communication is required.

To enable multi-hop communication, efficient forwarding algorithm needs to be employed, which reduces the overhead (in terms of both the generated message number and the delay), at the same time ensuring best possible delivery rates.

For majority of ITS applications, there is a relevant geographical location or zone to which information/messages need to be delivered (e.g., a region of interest in case of emergency breaking notification). For this reason, most forwarding algorithms in vehicular networks rely on geographic forwarding, which means that they use the geographical location of the vehicles to make forwarding decisions, as generally illustrated in Fig. 1.

There exist several metrics that can be utilized as a criterion for selecting the next-hop forwarders: hop count (for reference, see C. E Perkins, E. M. Royer: “Ad-hoc on-demand distance vector routing”, Mobile Computing Systems and Applications, 1999, Proceedings, WMCSA'99, Second IEEE Workshop on, pp. 90-100, IEEE), distance (for reference, see B. Karp, H. T. Kung: “GPSR: Greedy perimeter stateless routing for wireless networks”, Proceedings of the 6th annual international conference on Mobile computing and networking, 2000, August, pp. 243-254, ACM), congestion (for reference, see X. Chen, H. M. Jones, A. D. S. Jayalath: “Congestion-aware routing protocol for mobile ad hoc networks”,Vehicular Technology Conference, September 2007, VTC-2007, IEEE 66th, pp. 21-25, IEEE), and delay (for reference, see H. Füßler, J. Widmer, M. Käsemann, M. Mauve, H. Hartenstein: “Contention-based forwarding for mobile ad hoc networks”, Ad Hoc Networks, 1(4), 351-369).

In all forwarding algorithms currently used in the European V2V standardized system, which implements the ITS network stack shown in Fig. 2 that interconnects two different OSI protocol stacks at layers 5 to 7 (as described in detail in document ETSI EN 302 665 V1.1.1 Intelligent Transport Systems (ITS); Communications Architecture, a skilled artisan is assumed to be sufficiently familiar with), distance is used for determining the optimal forwarder of a message. Furthermore, the standardized system adopts contention based forwarding, as described, e.g., in the last-mentioned citation, as one of the forwarding algorithms.

Furthermore, the standardized system also adopts greedy based forwarding, wherein the sending node explicitly selects the next hop, as described, e.g., in the last-mentioned citation, as another of the forwarding algorithms.

The above-mentioned forwarding algorithms are disadvantageous in that they have a rather limited view on the current network conditions, which in many cases leads to forwarding inefficiencies due to suboptimal forwarder selection.

In view of the above it is an objective of the present invention to improve and further develop a method for performing forwarding in a wireless ad hoc network, in particular vehicular ad hoc network, and a network node for deployment in a wireless ad hoc network of the initially mentioned type in such a way that the forwarder selection efficiency is improved and the likelihood of selecting forwarders that are suboptimal in terms of reducing congestion and delay in the network is reduced.

In accordance with the invention, the aforementioned object is accomplished by a method comprising the features of claim 1. According to this claim such a method is characterized in that it comprises collecting information about delays induced by layers below said forwarding algorithm, wherein said forwarding algorithm takes into consideration said collected delay information for selecting a next hop forwarder node.

Furthermore, the above object is accomplished by a network node comprising the features of claim 17. According to this claim such a network node is characterized in that it comprises means for collecting information about delays induced by layers below said forwarding algorithm, wherein said forwarding algorithm is configured to take into consideration said collected delay information for selecting a next hop forwarder node.

According to the invention it has been recognized that efficient and appropriate selection of a forwarder (or multiple forwarders) can be made by considering information such as lower-layer delays. The information about the delay induced by the layers below the forwarding algorithm is utilized and the forwarding decision is adjusted accordingly in order to select the appropriate forwarder(s). In the presence of significant lower layer delays and without applying the present invention, the forwarding algorithm might be unable to select correct forwarder, thus resulting in suboptimum performance (increased overhead, contention, and collisions).

Consequently, embodiments of the present invention, by providing cross-layer, congestion aware enhancements for message forwarding, solve the problem of forwarding inefficiencies due to the forwarding algorithm not being aware of the delays introduced by the layers below the forwarding layer. Specifically, the present invention provides a cross-layer method for assisting the forwarding algorithm (or the forwarding algorithm itself) that enables efficient forwarder selection in the presence of lower-layer delays. According to the invention it has been recognized that delay generated by mechanisms other than forwarding algorithm can be conveniently anticipated and provided to the forwarding algorithm to improve the forwarding efficiency. In particular, for both sender- and receiver-based forwarding algorithms, the proposed solution improves the forwarder selection by reducing the likelihood of multiple unwanted forwarders, consequently reducing the congestion and delay in the system.

Embodiments of the present invention can be suitably applied in connection with the targeted standards in the ETSI and C2C-CC standardization bodies, which describe architectures with contention-based and greedy-based forwarding and access-layer delays introduced by congestion control. By applying the present invention, the result is improved forwarding in terms of reduction of multiple unwanted forwarders, reduced congestion, and increased reliability. For any other system with contention-based or greedy-based forwarding and with delays caused by lower layers, the invention improves the forwarder selection.

According to a preferred embodiment forwarding may be performed by applying contention-based forwarding. In this case a selection of one or more appropriate forwarder nodes may be performed by introducing forwarding delays that discriminate between potential forwarder nodes, wherein the forwarding algorithm takes into consideration the collected delay information for calculating adjusted forwarding delays.

According to another embodiment forwarding may be performed by applying greedy-based forwarding. In this case an appropriate forwarder node may be explicitly selected by taking into consideration at least the amount of lower layer delay experienced by the network nodes.

According to a preferred embodiment the forwarding algorithm may either be a receiver-based forwarding algorithm or a sender-based forwarding algorithm. Generally, the present invention may be applied in connection with any forwarding method where forwarder discrimination is performed using delay as the main metric and where any (significant) lower-layer delays exist.

According to a preferred embodiment the delay information employed by a network node may include, but is not limited to, information on MAC protocol delays, queuing delays and/or delays due to congestion control. Alternatively or additionally, the delay information employed by a network node may include information that is locally available at the network node, in particular information on the distance to the destination and on the progress distance from the sender of a message (previous hop), information on current lower layer delays, and/or information on the number of neighbored network nodes.

If available, the delay information employed by a network node may also include information on delays of neighbored network nodes, and/or information on a residual delay from the ego network node and neighbored network nodes. In this case it is possible to make more precise decisions for forwarder selection.

Still further, the delay information employed by a network node may include information on channel congestion.

According to preferred embodiment, in case the number of neighbored network nodes is below a predefined threshold and the level of channel congestion is below a predefined threshold, the forwarding delay may be adjusted to be set to a predefined minimum value.

According to another preferred embodiment, in case the number of neighbored network nodes is above a predefined threshold, the forwarding delay is decreased the higher the progressed distance from a sender towards a destination. In this scenario, in case the level of channel congestion is below a predefined threshold, the forwarding delay calculation may be performed by assigning the progressed distance a higher weight than the lower layer delay. On the other hand, in case the level of channel congestion is above a predefined threshold, the forwarding delay calculation may be performed by assigning the lower layer delay a higher weight than the progressed distance.

According to a preferred embodiment, in case progressed distance from a sender towards a destination is below a predefined threshold, the forwarding delay may be adjusted to be set to a predefined maximum value.

According to a preferred embodiment, the execution of the forwarding algorithm is triggered by a network node receiving a request to determine a next forwarder node.

According to a preferred embodiment, the forwarding algorithm may be applied for messages related to delay tolerant applications, which in case of VANETS may include traffic, infotainment, or the like. On the other hand, in case of safety critical messages the forwarding delays may be set to a predefined minimum value. In this regard it should be noted that, although safety critical messages are handled by other mechanisms instead of applying the forwarding algorithm, safety critical messages benefit indirectly from the present invention since it is congestion aware and prevents broadcast storms.

According to a preferred embodiment, similar to the case of safety critical messages, forwarding delays may be set to a predefined minimum value in case of first hop forwarding.

There are several ways how to design and further develop the teaching of the present invention in an advantageous way. To this end it is to be referred to the patent claims subordinate to patent claims 1 on the one hand and to the following explanation of preferred embodiments of the invention by way of example, illustrated by the drawing on the other hand. In connection with the explanation of the preferred embodiments of the invention by the aid of the drawing, generally preferred embodiments and further developments of the teaching will be explained. In the drawing

Fig. 1 is a schematic view illustrating the general concept of geographical forwarding in a VANET,

Fig. 2 is a schematic view illustrating the general ETSI ITS network stack,

Fig. 3 is a schematic view illustrating a basic forwarder selection scenario in a VANET,

Fig. 4 is a schematic view illustrating a forwarder selection scenario in a VANET with multiple forwarders being selected,

Fig. 5 is a schematic view illustrating a forwarder selection scenario in a VANET with high congestion and low reliability, and

Fig. 6 is a high-level flowchart of an embodiment of the present invention.

Fig. 3 is a schematic view illustrating a basic forwarder selection scenario in a VANET, where a receiver-based forwarding algorithm based on contention delays is assumed. In this scenario, the source of a message (in Fig. 3 of the network node illustrated by the dark rectangle) sends out a message in broadcast. The receivers/forwarders of a message determine a contention period and buffer the message for the selected contention period. The smaller their distance to a destination, the shorter the contention period is.

Specifically, in case of receiver- and delay-based forwarding, when a vehicle receives a message that needs to be forwarded, it uses its distance from the destination area to determine how long it will delay its transmission. The closer it is to the destination area, which in Fig. 3 is illustrated by the circle indicating a region of interest (ROI), the less the delay will be. For example, in Fig. 3, because it is closer to the ROI, network node 1 will select the lowest delay, and will therefore forward before network nodes 2 and 3. Consequently, network nodes 2 and 3 may choose to suppress their own transmissions, when they receive the rebroadcasted message from network node 1, in order to reduce the forwarding overhead.

A problem arises when there exist other delays in the network/system, which can interfere with the forwarding algorithm. For example, there might be a congestion control algorithm in place on the medium access control layer (MAC), which determines the minimum delay between subsequent messages from a vehicle. It should be noted here that only the delays generated at the layers below networking, e.g., access layer, are relevant. Similarly, the MAC protocol itself might introduce considerable delay (e.g., TDMA-based MAC protocols). In such cases, the following problems in the delay-based forwarding algorithms can occur:

- Multiple unwanted transmissions by potential forwarders: This may result in the suppressing scheme of forwarded message being interrupted, which in turn may potentially cause a broadcast storm.
- Suboptimal forwarder selection: The forwarding algorithm chooses the optimal forwarder in terms of progress made from source to destination. The additional delays can cause that a node close to the source is chosen as forwarder. This can lead to increased number of hops, i.e. unnecessary increase in rebroadcasts.
- Decreased reliability: The increase in number of forwarded messages can lead to increased load and consequently packet losses.

The consequences for the network are increased delay and congestion. The increased number of forwarded messages will additionally increase the channel load, which in turn activates congestion control. In case there is no congestion control, the channel gets overloaded and collisions can happen. In case there is congestion control, this can increase the communication delays further, possibly also resulting in message blocking (i.e., not allowing some messages onto the channel).

One example is described in connection with Fig. 4, where, due to MAC (L2) delays (denoted L2 T_{off}), multiple vehicles deem themselves as suitable forwarders. Each node will select a suitable layer 3 delay based on its distance to the ROI. In the illustrated embodiment this (contention based forwarding, cbf) delay is lowest for network node 1 (L3 T_{cbf} = 10 ms), which is located close to the ROI, and is highest for network node 4 (L3 T_{cbf} = 650 ms), which has the greatest distance to the ROI. Once that delay expires the message is queued at layer 2, without the possibility to be interrupted. This is indeed the case with most practical systems, since the medium access and physical layer are usually handled by NIC (Network interface controller). Due to the different granularity of the delays at layers 2 and 3, the order of suitable forwarders will not be determined by layer 3 anymore. As a consequence, network nodes 1, 2, 3 and 4 will forward the message, instead of network node 1 only, which would be the original intention of the forwarding algorithm.

Another example, which is depicted in Fig. 5, shows a case of increasing the channel load in congested areas. In the illustrated scenario, the ROI is outside of the communication area (indicated by the dotted line) of the source. The source sends a message in broadcast, which is received by network nodes 1, 2, 3, and 4, located within the communication area of the source. Network nodes 4, 5, 6, and 8 are assumed to have much lower layer 2 delays (L2 T_{off} = 95 ms) than network nodes 1, 2, 3, and 7 (L2 T_{off} = 1000 ms). Therefore, the packet will be forwarded via these network nodes. On the other hand, the shorter route via network node 1 and network node 7 becomes congested additionally, while never being used.

While the examples described above are related to receiver-based forwarding algorithms, similar problems might occur in connection with sender-based forwarding algorithm. In sender-based forwarding algorithm based on contention delays the source/sender of a message selects the next hop forwarder, based on the smallest geographical distance to destination. The message is then unicast towards the selected forwarder.

In case of the presence of the above mentioned layer 2 delays, a problem of reduced reliability can occur, since a forwarding node/path that is chosen may have significant delays/congestion. Second, further hop forwarded messages may be dropped due to congestion. As only a single forwarder is selected that can lead to reduced reliability. Moreover, a problem of increased delay may occur, since the chosen forwarder/path may introduce significant delays compared to existing alternative paths.

In order to address these problems, embodiments of the present invention relate to an improvement of forwarding decisions in the presence of delays introduced by any entity residing below the forwarding layer (i.e. layer 3). In case of contention-based forwarding, where forwarding delay is used to discriminate between potential forwarders, introduction of delays not generated by the forwarding algorithm can invalidate contention-based decision making, as explained in the examples above. Therefore, embodiments of the present invention incorporates any extraneous delay, along with any other cross-layer information that might be available and useful (e.g., number of surrounding neighbors, channel load, etc), to solve the problem of forwarding inefficiencies due to the forwarding algorithm not being aware of these delays. In particular, for both sender- and receiver-based forwarding algorithms, the proposed solution improves the forwarder selection by reducing the likelihood of multiple unwanted forwarders, consequently reducing the congestion and delay in the system.

Fig. 6 is a high-level flowchart related to an embodiment of the present invention. As illustrated in step 601, the mechanism is triggered by a network node receiving a request to determine a next forwarder network node.

First of all, illustrated in step 602, the network node calculates the relevant distance values, which includes both the distance to the destination of the respective message and the progress distance from the sender of the message (i.e. from the previous hop) towards the destination. Generally, network nodes may derive these distances from information contained in their neighbor location tables.

In the next step 603, the network node collects extraneous delay caused by lower layers, for instance, MAC protocol delays, queuing delays, delays due to congestion control, etc. Optionally, as shown in steps 604, 605, the network node may collect other cross-layer information that might be available and useful, for instance information on the number of surrounding neighbors, channel load, etc.

After having collected all available relevant information, in step 606, the network node checks whether the message is a safety critical message or whether it is the first hop forwarding. If one of the conditions is fulfilled, the network node sets its forwarding delay (denoted “myDelay” in Fig. 6) to a predefined minimum delay (denoted “minDelay” in Fig. 6) and makes a corresponding forwarding decision in step 609.

If the message is neither a safety critical message, nor it is the first top forwarding, in step 608, the network node calculates its network layer delay using a function f(αi1,…, vin). Again, in step 609, the network node sets the delay to make the forwarding decision.

According to one embodiment the function f(αi1,…, vin) may take the following form:

Input parameters $i_{1...n}$ for the function f may be specified as follows:

- Distance to destination: dist
- Progress distance (distance from sender towards destination): progDist
- Lower layer delay: toff
- Number of neighbors: numNeigh
- Maximum forwarding delay: maxDelay

The following thresholds may be defined:

- Progress thresholds: progMax (e.g. 200-500m); progMin (e.g. 30m)
- Distance threshold: distMax (e.g. 200-500m, similar to typical communication range values)
- Lower layer delay thresholds: toffMin (e.g. 60ms); toffMax (e.g. 500ms)
- Number of neighbors threshold: neighMin (e.g. 3-5), used to distinguish between sparse and non-sparse neighborhood

The following weights α, …, v may be defined:

- Distance to destination weight: a
- Progress distance weight: b
- Lower layer delay weight: c

Calculation may be performed as follows:

- delay due to distance: distDelay. distDelay = a*dist + b*progDist
- delay due to lower layer delay: lowerDelay. lowerDelay = c*toff

Output (as output, the function generates the network layer delay that affects the chance of a network node becoming a forwarder):

- Forwarding delay: fwdDelay

Based on the above definitions the following scenarios can be envisioned:

In case of the receiving a multihop packet p, which is not a duplicate, and *dist < distMax* , it can be assumed that the network node should be in communication range of the destination. Therefore, all forwarders are suitable and the forwarding delay can be defined as *fwdDelay =~= toff*.

Otherwise, i.e. in case the network node is outside of communication range of the destination, the delay is calculated based on distance, lower delay, progress from sender, and/or number of neighbors with different weights. By adding lowerDelay forwarding will be disrupted, i.e., it cannot be ensured that any progress (from sender) is made. Therefore, the progress distance may be added to the calculation as follows:

*fwdDelay = distDelay (a*dist + b*progDist) + lowerDelay (c*toff)*

If *progDist < progMin* , i.e. below a certain progress distance *progDist*, a network node is no suitable forwarder, since it is located too close to current sender and the progress towards the destination is thus minimal. Therefore, a high weighting factor b is used for the progress delay (e.g. b = 1). By setting the network delay to a high value (*fwdDelay = maxDelay*), the network node forwards the message only in case no other network node forwards it. Instead of simply setting weighting factor b = 1, the information on the number of neighbors can be used and b can be increased, the lower the number of neighbor to network nodes (*numNeigh*).

Otherwise (i.e., the progress distance is above a threshold value), the vehicle/network node checks if the number of neighbors it has is low (e.g. *numNeigh < neighMin*) and if its own congestion is low (e.g. *toff < toffMin*); if this is the case, there is no danger of a broadcast storm, and the network delay is set to a minimum value, i.e. no additional delays are introduced (*fwdDelay =~= distDelay*). This may result in more than one forwarder rebroadcasting the message, but the number of rebroadcasts and effect on the system is limited due to the low neighbor density and low congestion.

In case when there are more neighbors, but the congestion remains low (e.g. *toff < toffMin*, *numNeigh > neighMin*), the more progress to the destination the vehicle has, the higher the likelihood of forwarding the message. In other words, for network nodes that made a lot of progress towards the destination, the delay will be minimized in order to increase the probability of being chosen as forwarders:

$$fwdDelay = a*dist + c*toff, \qquad with\ (a>c)$$

Finally, if the measured congestion is above a defined threshold (e.g. toff > toffMax), the vehicle/network node calculates its network-level delay using the combination of the congestion value, the progress distance, and the distance to destination, where both of these values are weighted, with all the weights ranging from 0 to 1. In this case of a congested channel, more weight is given to toff time, i.e. more congested nodes get even more delay to prevent broadcast storm:

$$fwdDelay = a*dist + c*toff, \qquad with\ (a<c)$$

The above described mechanism allows receiver-based forwarding algorithms using contention to adjust their network layer delays in order to make the optimal forwarding decision in terms of overhead, low congestion, and delay. The used input parameters can be utilized by sender-based forwarding algorithms as well. In such case, all the decisions will be made by a single entity (the forwarder) and can be based on the local congestion information, number of neighbors, distance to destination, and distance to sender of each neighbor. Such information is usually available in the neighbor location table. The main challenge for the sender-based algorithm would be to increase reliability of the forwarding, by finding the optimal route in terms of network density and congestion. Choosing a low density route or a congested route may result in packet loss.

Similarly, for greedy-based forwarding in the presence of lower-layer delays, the selection of next hop that has high lower-layer delay can result in forwarding a message over, e.g., a congested area with higher chance of message contention, delay, and message loss. Therefore, embodiments of the present invention introduce a cutoff for lower-layer delay: if the potential next-hop node has the lower-layer delay above the predefined threshold, that node should not used as next hop.

With respect to applications of embodiments of the present invention and the field of ITS, it should be noted that the problems described above occur with the reference systems proposed by both ETSI and the Car 2 Car Communication Consortium (C2C-CC). Therefore, the improvements achieved by embodiments of the present invention specifically affect the following standards:

- ETSI TS 102 636-4-1 (Intelligent Transport Systems (ITS); Vehicular communications; GeoNetworking; Part 4: Geographical addressing and forwarding for point-to-point and point-to-multipoint communications; Sub-part 1: Media-Independent Functionality)
- ETSI TS 102 636-4-2 (Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; Part 4: Geographical addressing and forwarding for point-to-point and point-to-multipoint communications; Sub-part 2: Media-dependent functionalities for ITS-G5)
- ETSI TS 102 687 (Intelligent Transport Systems (ITS); Decentralized Congestion Control Mechanisms for Intelligent Transport Systems operating in the 5 GHz range; Access layer part)
- CAR 2 CAR Communication Consortium - C2C-CC Basic System Standards Profile v1.0

ETSI TS 102 636-4-1 contains the proposed forwarding schemes that are to be used in both ETSI and C2CCC reference systems.

ETSI TS 102 636-4-2 specifies media-dependent functionalities for GeoNetworking when using the ITS access technology ITS-G5. GeoNetworking is the protocol suite to be used by both ETSI and C2C-CC reference systems; same applies for ITS access technology ITS-G5.

C2C-CC Basic System Standards Profile as well as ETSI TS 102 687 define a congestion control algorithm that operates on the access layer. Both solutions introduce minimum inter-message delay to control the congestion on the channel. The value of the inter-message delay varies as a function of observed channel load. In all cases, the delay introduced is approximately an order of magnitude larger than the delay used for making forwarding decisions (defined in ETSI TS 102 636-4-1). So far, this delay has not been taken into account by the forwarding algorithms proposed in ETSI (which are also used in C2C-CC). By not accounting for delay, the forwarding algorithms are likely to make suboptimal forwarding decisions, resulting in multiple unwanted forwarders, high congestion, and low reliability (as explained above in connection with Figs. 5 and 6).

Many modifications and other embodiments of the invention set forth herein will come to mind the one skilled in the art to which the invention pertains having the benefit of the teachings presented in the foregoing description and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

Claims

1. Method for performing forwarding in a wireless ad hoc network, in particular vehicular ad hoc network, by means of a forwarding algorithm,
characterized in that the method comprises:
collecting information about delays induced by layers below said forwarding algorithm,
wherein said forwarding algorithm takes into consideration said collected delay information for selecting a next hop forwarder node.

2. Method according to claim 1, wherein forwarding is performed by applying contention-based forwarding, wherein a selection of one or more appropriate forwarder nodes is performed by introducing forwarding delays that discriminate between potential forwarder nodes, wherein said forwarding algorithm takes into consideration said collected delay information for calculating adjusted forwarding delays.

3. Method according to claim 1, wherein forwarding is performed by applying greedy-based forwarding, wherein an appropriate forwarder node is explicitly selected by taking into consideration at least the amount of lower layer delay experienced by the network nodes.

4. Method according to any of claims 1 to 3, wherein said forwarding algorithm is either a receiver-based forwarding algorithm or a sender-based forwarding algorithm.

5. Method according to claim 1 to 4, wherein said delay information collected by a network node includes information on MAC protocol delays, queuing delays and/or delays due to congestion control.

6. Method according to any of claims 1 to 5, wherein said delay information collected by a network node includes information that is locally available at said network node, in particular information on the distance to the destination and on

the progress distance from the sender of a message, information on current lower layer delays, and/or information on the number of neighbored network nodes.

7. Method according to any of claims 1 to 6, wherein said delay information collected by a network node includes information on delays of neighbored network nodes, and/or information on a residual delay from said network node and neighbored network nodes.

8. Method according to any of claims 1 to 7, wherein said delay information collected by a network node includes information on channel congestion.

9. Method according to any of claims 1 to 8, wherein, in case the number of neighbored network nodes is below a predefined threshold and the level of channel congestion is below a predefined threshold, said forwarding delay is adjusted to be set to a predefined minimum value.

10. Method according to any of claims 1 to 9, wherein, in case the number of neighbored network nodes is above a predefined threshold, said forwarding delay is decreased the higher the progressed distance from a sender towards a destination.

11. Method according to claim 10, wherein, in case the level of channel congestion is below a predefined threshold, said forwarding delay calculation is performed by assigning the progressed distance a higher weight than the lower layer delay.

12. Method according to claim 10, wherein, in case the level of channel congestion is above a predefined threshold, said forwarding delay calculation is performed by assigning the lower layer delay a higher weight than the progressed distance.

13. Method according to any of claims 1 to 12, wherein, in case progressed distance from a sender towards a destination is below a predefined threshold, said forwarding delay is adjusted to be set to a predefined maximum value.

14. Method according to any of claims 1 to 13, wherein the execution of said forwarding algorithm is triggered by a network node receiving a request to determine a next forwarder node.

15. Method according to any of claims 1 to 14, wherein said forwarding algorithm is applied for messages related to delay tolerant applications, and wherein forwarding delays are set to a predefined minimum value in case of safety critical messages.

16. Method according to any of claims 1 to 15, wherein forwarding delays are set to a predefined minimum value in case of first hop forwarding.

17. Network node for deployment in a wireless ad hoc network, in particular for executing a method according to any of claims 1 to 16, said network node being configured to execute a forwarding algorithm that selects of one or more appropriate forwarder nodes either explicitly or by introducing forwarding delays that discriminate between potential forwarder nodes,

c h a r a c t e r i z e d i n that the network node comprises:

means for collecting information about delays induced by layers below said forwarding algorithm,

wherein said forwarding algorithm is configured to take into consideration said collected delay information for selecting a next hop forwarder node.

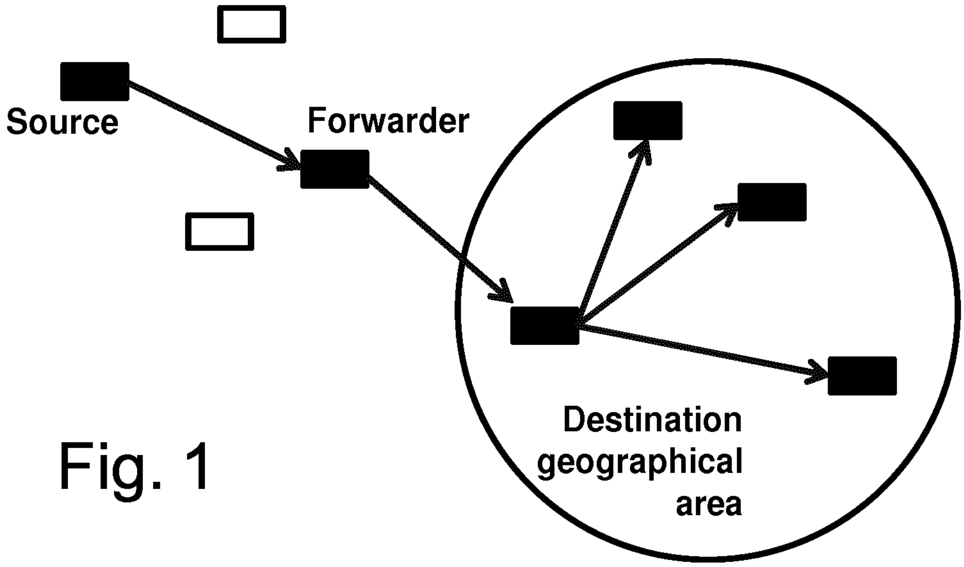
Source
Forwarder
Destination geographical area

Fig. 1

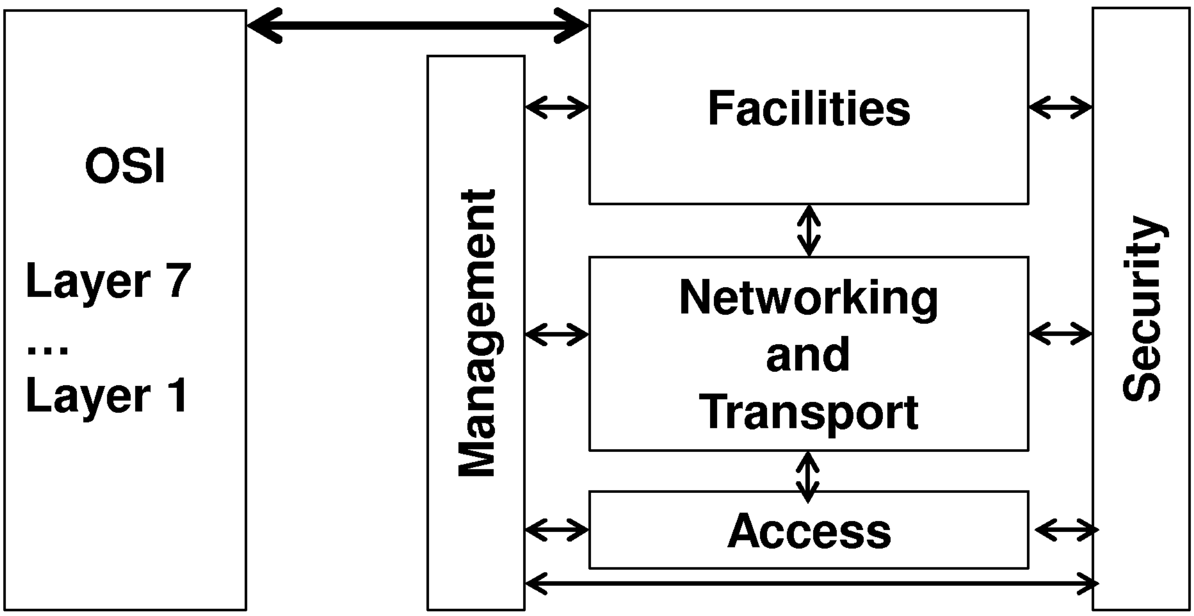
OSI
Layer 7
...
Layer 1
Management
Facilities
Networking and Transport
Access
Security

Fig. 2

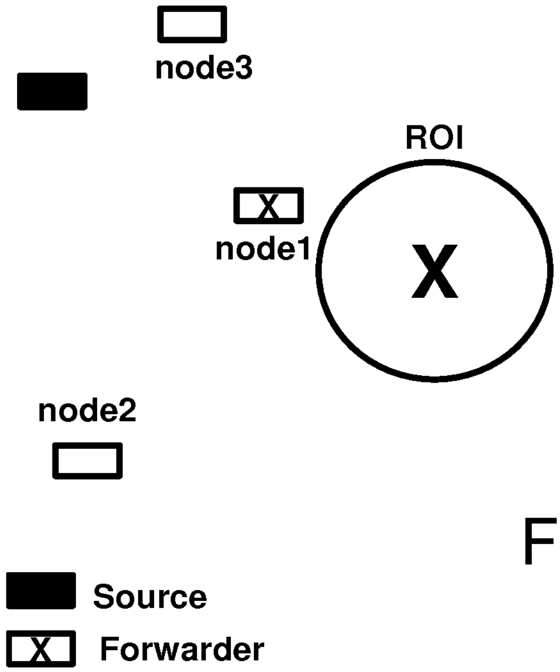

Fig. 3

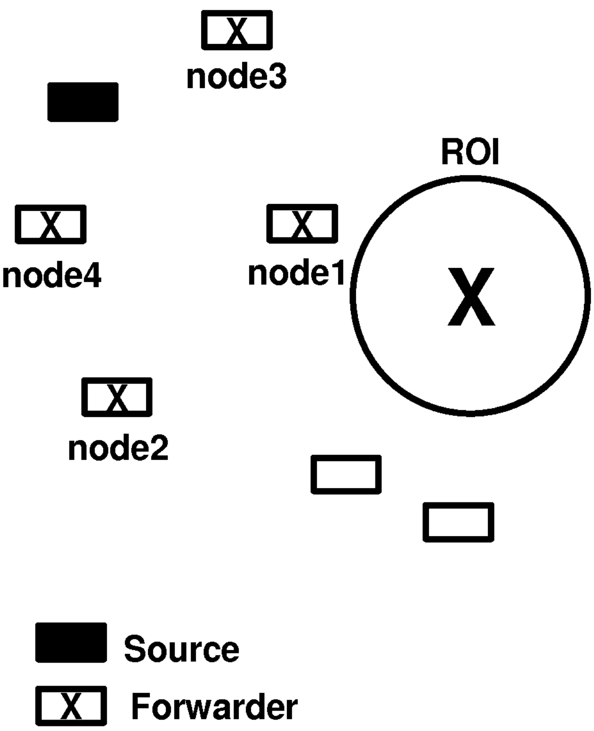

Fig. 4

	L3 Tcbf	L2 Toff
Node 1	10ms	95ms
Node 2	30ms	250ms
Node 3	50ms	250ms
Node 4	65ms	95ms

	L3 Tcbf	L2 Toff
Node 1	20ms	1000ms
Node 2	30ms	1000ms
Node 3	40ms	1000ms
Node 4	65ms	95ms
Node 5	50ms	95ms
Node 6	15ms	95ms
Node 7	10ms	1000ms
Node 8	10ms	95ms

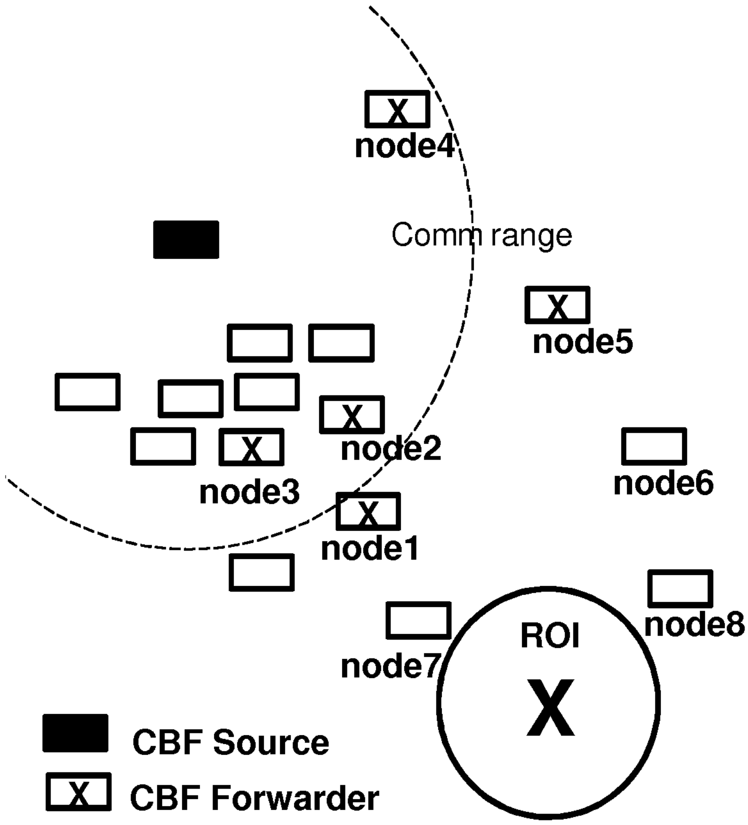

Fig. 5

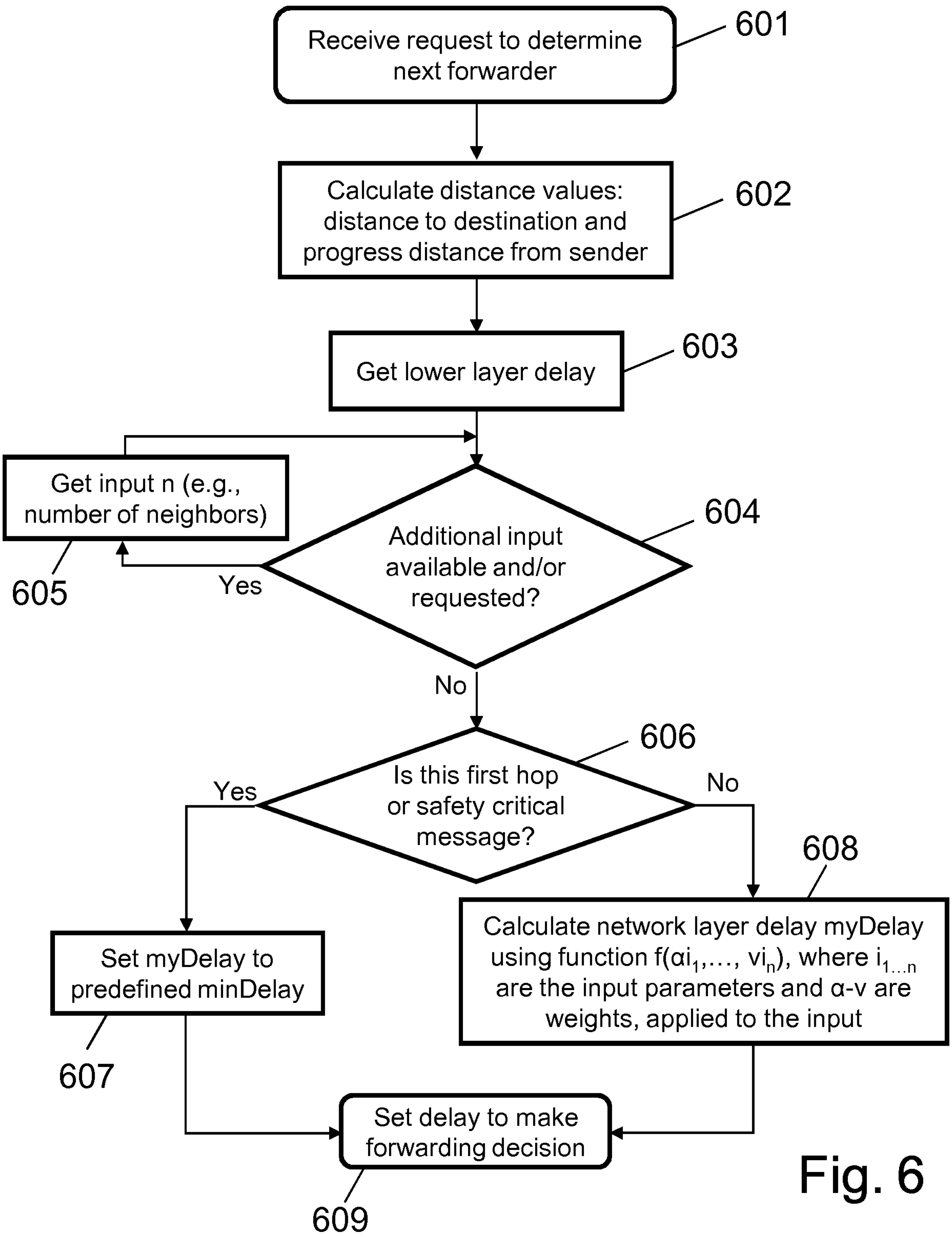
Receive request to determine next forwarder
601
Calculate distance values: distance to destination and progress distance from sender
602
Get lower layer delay
603
Get input n (e.g., number of neighbors)
605
Yes
Additional input available and/or requested?
604
No
Is this first hop or safety critical message?
606
Yes
No
Set myDelay to predefined minDelay
607
Calculate network layer delay myDelay using function f(αi1,…, vin), where i1…n are the input parameters and α-v are weights, applied to the input
608
Set delay to make forwarding decision
609

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/053653

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W40/04 H04W40/12 H04W40/20
ADD. H04W84/18 H04L12/727

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04W H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	XIAOQIN CHEN ET AL: "Congestion-Aware Routing Protocol for Mobile Ad Hoc Networks", VEHICULAR TECHNOLOGY CONFERENCE, 2007. VTC-2007 FALL. 2007 IEEE 66TH, IEEE, PI, 1 September 2007 (2007-09-01), pages 21-25, XP031147359, ISBN: 978-1-4244-0263-2 page 22, right-hand column -----	1-17

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 May 2015	09/06/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Tsuchiya, Kuni

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