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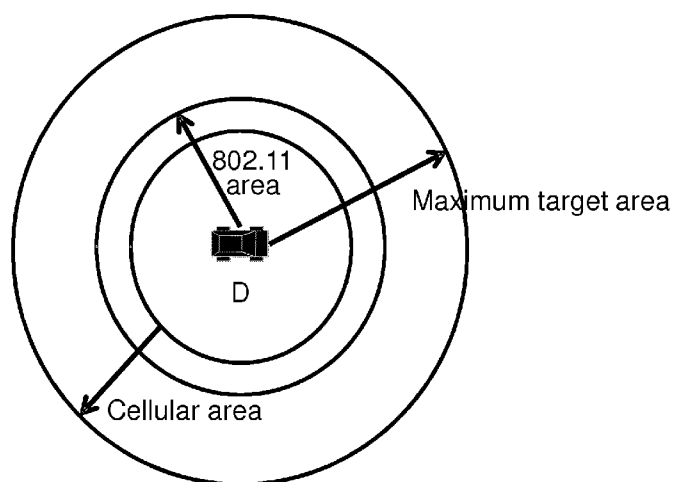


Fig. 2

(57) **Abstract:** A method for transmitting messages by nodes in a vehicular ad-hoc network (VANET), wherein the nodes are equipped with first communication means for operating via a cellular network - cellular transmissions - and with second communication means for operating via wireless local area network (WLAN) channels - 802.11 transmissions - and wherein said vehicular ad-hoc network includes a central entity that serves as a message reflector to enable cellular-based communication among the nodes of said vehicular ad-hoc network, is characterized in that a node dynamically selects the network to use for transmitting messages, wherein said network selection is performed in such a way that a predefined performance metric is optimized.

INTEGRATION OF CELLULAR AND IEEE 802.11 NETWORKS IN VANETS

The present invention relates to a method for transmitting messages by nodes in a vehicular ad-hoc network (VANET), wherein the nodes are equipped with first
5 communication means for operating via a cellular network – cellular transmissions – and with second communication means for operating via wireless local area network (WLAN) channels – 802.11 transmissions –, and wherein said vehicular ad-hoc network includes a central entity that serves as a message reflector to
10 enable cellular-based communication among the nodes of said vehicular ad-hoc network.

Furthermore, the present invention relates to a node for deployment in a vehicular ad-hoc network (VANET), the node being equipped with first communication
15 means for operating via a cellular network – cellular transmissions – and with second communication means for operating via wireless local area network (WLAN) channels – 802.11 transmissions –, wherein said vehicular ad-hoc network includes a central entity that serves as a message reflector to enable said cellular-based communication of the node with other nodes of said vehicular ad-
20 hoc network.

Vehicular networking is considered as an important technology in the area of Intelligent Transportation Systems (ITS). It allows vehicles to exchange information among each other to support various applications related to safety,
25 business, entertainment and others. Examples of such applications are collision avoidance or cooperative adaptive cruise control (cooperative ACC). Further, using vehicular networking, vehicles can also communicate with road-side infrastructure systems to attain useful information such as roadwork warning, weather warning, or information about available parking in a city.

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In the last decade, a vast amount of research has been done on short-range wireless vehicular networking where vehicles are equipped with communication devices according to the IEEE 802.11 standard (WLAN), such as IEEE 802.11/ITS-G5, to communicate with each other. In recent years, attention has

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been turned to how to leverage cellular networks such as 4G/LTE to support vehicular networking. An important aspect of cellular-based vehicular networking is that there is no direct communication link between a sender and a receiver at the lower layer (e.g., layer 2) such as in the case of IEEE 802.11-based vehicular
5 networking. Rather, vehicles have to rely on one or multiple network elements at higher layer (e.g., layer 3 or higher) to relay data. A design approach for cellular-based networking is to introduce a new network element that serves as a message reflector to facilitate the communication among vehicles. This network element functions as a server for the vehicles and road infrastructure, i.e., it processes
10 incoming messages from its clients (vehicles and road infrastructure) and redistributes these messages to them. Since this server is typically responsible for a geographical area, it is termed GeoServer. The main functionality of a GeoServer is to provide vehicles with geographical-related services such as safety- and commercial-related services.

15 Cellular-based vehicular networking and, for the sake of simplicity hereinafter briefly denoted 802.11-based vehicular networking, are complementary to each other and thus have different performance characteristics that can have an important impact on various ITS applications. 802.11-based vehicular networking
20 provides low delay, but can only cover short distances. When using multi-hop forwarding, 802.11-based vehicular networking can increase the distance of delivery but the reliability or reception rate tends to decrease. Cellular-based vehicular networking has better coverage than 802.11-based vehicular networking, but its latency tends to be higher than 802.11-based vehicular networking. Further,
25 since the bandwidth controlled by a base station is limited, cellular-based vehicular networking also faces scalability problem.

Integrating multi-hop 802.11 networks and cellular networks has been a hot topic during the recent years. However, most of the related work assumes cooperation
30 between the multi-hop and cellular networks at lower layers, such as G. Fodor, E. Dahlman, G. Mildh, S. Parkvall, N. Reider, G. Miklos, and Z. Turanyi: "Design aspects of network assisted device-to-device communications", IEEE Commun. Mag., vol. 50, no. 3, pp. 170-177, Mar. 2012, which is difficult to implement in practice because existing communication standards need to be modified.

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In view of the above it is an objective of the present invention to improve and further develop a method for transmitting messages by nodes in a VANET and a corresponding node for deployment in a VANET of the initially described type in
5 such a way that routing decisions are optimized at multiple entities to reliably and effectively disseminate information in geographical areas without the need for modifying existing communication standards.

In accordance with the invention, the aforementioned object is accomplished by a
10 method comprising the features of claim 1. According to this claim such a method for transmitting messages by nodes in a VANET is characterized in that a node dynamically selects the network to use for transmitting messages, wherein said network selection is performed in such a way that a predefined performance metric is optimized.

15 Furthermore, the above mentioned objective is accomplished by a node comprising the features of claim 25. According to this claim such node for deployment in a VANET is characterized in that the node is configured to perform dynamic selection of the network to use for transmitting messages in such a way
20 that a predefined performance metric is optimized.

According to the present invention it has been recognized that a particularly reliable and effective dissemination of information in geographical areas can be achieved by combining cellular-based and 802.11-based vehicular networking.
25 The combination is performed in such a way that a predefined performance metric is optimized in order to address the problems of latency, coverage, and reception rate for ITS applications. By considering the advantages and disadvantages of 802.11 and cellular networks, the best possible routing decisions can be achieved. As a result, the present invention enables optimized routing decisions to be taken
30 and executed jointly by the centralized entity and the distributed entities (vehicles) to disseminate information in geographical areas.

As a further advantage, the method according to the present invention can be executed at the application level, hence no modifications to the existing protocol

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stack is necessary. Still further, by combining both 802.11 and cellular networks in accordance with the present invention the bandwidth consumption of the cellular network is lowered, which is advantageous per se, given that the bandwidth of cellular networks is limited and expensive.

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Since in vehicular ad-hoc networks as addressed by the present invention, the communication nodes are arranged in vehicles, hereinafter the terms "node" and "vehicle" will be used synonymously.

- 10 According to a preferred embodiment the performance metric is selected to be information depreciation, which is aimed to be minimized. Information depreciation is regarded as one possible metric to measure the newness or freshness of the information that is stored at each vehicle. It is noted that information depreciation is one of many possible performance metrics that can be used for optimizing ITS
- 15 application performance. Other performance metrics such as delay and packet loss can be used and appropriately modeled as well. Generally, information depreciation is defined as the maximum difference between the current time and the time when the information has been gathered at the vehicle (or, correspondingly, at the central entity) and sent out to the central entity (or,
- 20 correspondingly, to the vehicle).

- With respect to optimal performance results, the performance metric will be independently calculated or estimated for each pair of source and destination nodes. From the perspective of an individual node, this means that the node
- 25 calculates or estimates the performance metric, e.g. the information depreciation, independently for each destination node it communicates with.

- In vehicular communications, a message can have its destination characterized by a geographical area, number of hops, or dedicated receiving vehicle. A maximum
- 30 target area can be regarded as an area that contains all the possible target areas for different messages, corresponding to a specific vehicle as the sender. According to a preferred embodiment a maximum target area of a node is split into two communication sub-areas, including a cellular area, which contains receiving nodes for which cellular transmissions outperform 802.11 transmissions in terms

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of the relevant performance metric, and a 802.11 area, which contains receiving nodes for which 802.11 transmissions outperform cellular transmissions in terms of the relevant predefined performance metric.

- 5 Advantageously, the nodes and the central entity, upon receiving a new message, estimate the predefined performance metric based on available control and feedback information, both with respect to cellular transmissions and with respect to 802.11 transmissions, and perform an optimization process both for the cellular area and the 802.11 area. In other words, a network selection mechanism is
10 applied that essentially determines the cellular area and the 802.11 area for each node.

According to an embodiment, the cellular areas for all vehicles are specified by the central entity according to historical data regarding the relevant performance
15 metrics, in particular information depreciation, of both 802.11- and cellular-based transmissions, wherein some data may be obtained via feedback from vehicles. The 802.11 area may be determined by each vehicle according to control and feedback information from the central entity and its neighboring vehicles, as well as its own measurements on depreciation, link status, etc.

20 A specific method for determining the 802.11 and cellular areas can be a fully centralized mechanism where the central entity determines both areas according to feedback information from vehicles, and transmits the result to each vehicle. Another specific method can be a distributed mechanism for determining the
25 802.11 area, in which the central entity only transmits some necessary control information (such as the current cellular area) to each vehicle, and each vehicle determines the 802.11 area for itself. These two methods can be adaptively selected according to the network condition. In both cases, the cellular area is determined by the central entity, because it has to process and forward all
30 messages that are sent via the cellular network.

To ensure successful message transfer, the cellular area and the 802.11 area may be generated in such a way that they have an overlapping part with each other.

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The size of the overlapping part may depend on the uncertainty of the relevant performance metric estimation/calculation.

To assist the determination of the two communication sub-areas, it may be provided that each node gathers information on delay and packet loss rates of packets received from the cellular network within a specific time window. Furthermore, the nodes may gather information on single-hop delay and packet loss rates of packets received from all respective neighboring nodes transmitted via the 802.11 network within a specific time window. The length of the time window may be selected depending on the channel variation and the desired accuracy of estimation. A longer time window leads to higher estimation accuracy but also increases the response time to channel variation, and vice versa.

With respect to an effective transmission of the gathered information, the nodes may insert the gathered information into regular packets as control and feedback information. In other words, each vehicle inserts the measurement results into packets that carry actual vehicular application information. To reduce additional communication overhead, it is possible that not all packets carry control and feedback information, i.e. control and feedback information may only be attached to some of the packets.

The determination of the different communication sub-areas by means of the above-mentioned optimization process may also consider the delay in transmitting control and feedback information. In other words, the optimization mechanism may ensure that the entire maximum target area is always covered by either the 802.11 or cellular area. This objective may be achieved by implementing a suggested expansion of a communication area resulting from the optimization process immediately by the respective node. On the other hand, a suggested diminution of a communication area resulting from the optimization process may be implemented by the respective node only after a delay of configurable duration. For instance, the duration of this delay may depend on the message transmission delay.

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For the above purpose, the central entity may maintain two cellular areas, one is obtained from the optimization algorithm (referred to as optimal cellular area), and the other is the area used for actual transmission (referred as actual cellular area). Similarly, each vehicle could maintain these two 802.11 areas.

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In addition or alternatively to the above, it may be provided that each vehicle stores a reverse 802.11 area. Unlike the original 802.11 area as discussed above, which specifies the area to which messages should be transmitted via the 802.11 network seen from a sender, the reverse 802.11 area considers the receiver side.

10 The reverse 802.11 area at a particular vehicle includes those vehicles which have that particular vehicle in their original 802.11 area.

To ensure effective forwarding of messages, at the vehicle side a forwarding algorithm may be executed that includes, by the respective node, checking
15 whether the sender of a received message belongs to its reverse 802.11 area and whether it belongs to the target area of the message received from the sender. In case that both checks yield positive results and the respective node has not yet received the message beforehand, the node may forward the received message after a time interval. The time interval may be introduced in order to avoid causing
20 a broadcast storm.

On the other hand, at the central entity, upon receiving a message from a node via the cellular network, a forwarding algorithm may be executed that includes, by the central entity, checking whether there is an intersection between the target area of
25 the received message and the actual cellular area of the respective sender of the message, and in case the check yields a positive result, forwarding the received message after a time interval to nodes within the intersection either using multicast/broadcast messages or per multiple unicast messages. In this regard it may be provided that the central entity selects one node within the intersection to
30 receive the messages via the cellular network, wherein the selected node then forwards the messages to the other nodes within said intersection via the 802.11 network.

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According to a preferred embodiment the central entity may be a GeoServer. In other words, the GeoServers that are deployed in current VANETs as central coordinators where all data are processed and that are required for cellular-based vehicular networking anyway can be employed to take over the functionality of the central entity as described in connection with the present invention.

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 claim 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

15

Fig. 1 is a schematic view of a general application scenario of a method in accordance with an embodiment of the present invention,

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Fig. 2 is a schematic view illustrating the process of determining different communication areas in accordance with an embodiment of the present invention,

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Fig. 3 is a diagram illustrating the procedure of communication area determination both at the vehicle and at a GeoServer in accordance with an embodiment of the present invention,

Fig. 4 is a state transition diagram for a vehicle's forwarding procedure in accordance with an embodiment of the present invention,

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Fig. 5 is a state transition diagram for a GeoServer's forwarding procedure in accordance with an embodiment of the present invention, and

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Fig. 6 is a schematic view illustrating a process of control and feedback information exchange in accordance with an embodiment of the present invention.

5

The present invention addresses VANET scenarios where cellular and 802.11 networks coexist, as illustrated in Fig. 1. In the example in Fig. 1, it is assumed that vehicles/nodes A, B, C, D, and E can be connected by 802.11 network in a hop-by-hop basis, as indicated by the dotted line arrows. Meanwhile, each node is
10 also connected via a base station 1 of an operator network 2 to the cellular network. The corresponding wireless communication is indicated by the dashed line arrows, while the wired connection between the base station 1 and the operator network 2 or the Internet 3, respectively, is indicated by solid line arrows. An essential component of the cellular network is a central server 4, which
15 processes incoming messages from its clients (vehicles and road infrastructure) and redistributes these messages to them and which in the embodiment of Fig. 1 is implemented in form of a GeoServer 5.

As is evident from Fig. 1, when, e.g., node D transmits a message, it has several
20 choices: it can transmit the message either via the cellular network, via 802.11 network (possibly in a multi-hop way) or via both.

It is noted that generally the one-hop transmission delay of IEEE802.11-based networks is smaller than the delay of cellular networks. However, 802.11-based
25 single hop transmissions can generally not cover the whole target area, which means that multi-hop transmissions are necessary. With multi-hop transmissions, the total delay and the packet loss rate increases with the number of hops. When the number of hops becomes large, 802.11-based multi-hop transmission may underperform cellular network transmission. Therefore, the present invention
30 proposes a method to dynamically select the network to use for transmitting messages for vehicular applications in such a way that a particular performance metric is optimized. While different performance metrics can be applied in a similar way, hereinafter an embodiment of the present invention is described in more

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detail, which is directed to minimizing information depreciation and which thus aims at keeping information as new as possible.

Let $p_{\text{single},i,w}$ be the single-hop packet loss probability corresponding to link i for the 802.11 network; the packet loss probability for 802.11 network over m hops will be $p_{m,w}$. While it is difficult to estimate the number of forwarding hops, some practical rules can be applied (e.g., $m = \text{DisseminationDistance} / \text{DistanceForOneHopCommunication}$, where $\text{DistanceForOneHopCommunication}$ is estimated from measurements or is fixed to a pre-defined value).

10

Thus, the packet loss probability for m hops can be expressed as:

$$p_{m,w} = 1 - (1 - p_{\text{single},1,w}) (1 - p_{\text{single},2,w}) \dots (1 - p_{\text{single},i,w}) \dots (1 - p_{\text{single},m,w})$$

15 To have at least one packet arriving at the destination, the expected number of transmissions for the 802.11 network over m hops will be:

$$N_{\text{Trans}_{m,w}} = (1 - p_{m,w}) + 2p_{m,w}(1 - p_{m,w}) + 3p_{m,w}^2(1 - p_{m,w}) + 4p_{m,w}^3(1 - p_{m,w}) + \dots = 1/(1 - p_{m,w})$$

20

If a station chooses to transmit its message over the cellular network, the packet loss probability is calculated as:

$$p_c = 1 - (1 - p_{\text{up}})(1 - p_{\text{down}}),$$

25

where p_{up} and p_{down} are the packet loss probability in the uplink and downlink direction.

30 To have at least one packet arriving at the destination, the expected number of transmission over cellular network is:

$$N_{\text{Trans}_c} = (1 - p_c) + 2p_c(1 - p_c) + 3p_c^2(1 - p_c) + 4p_c^3(1 - p_c) + \dots = 1/(1 - p_c)$$

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As mentioned already above, the illustrated embodiment aims to minimize the information depreciation, which is regarded as one possible metric to measure the newness or freshness of the information that is stored at each vehicle. It is once again noted that information depreciation is only one of many possible
 5 performance metrics that can be used for optimizing ITS application performance. Other performance metrics such as delay and packet loss can be used and appropriately modeled as well.

Information depreciation is defined as the maximum difference between the
 10 current time and the time when the information has been gathered at the vehicle (or, correspondingly, the GeoServer) and sent out to the GeoServer (or, correspondingly, the vehicle). Mathematically, the information depreciation is defined as the following:

15 The depreciation when using (possibly multi-hop) 802.11 network transmission is:

$$\text{Depreciation}_w = \text{PacketInterval} * N\text{Trans}_w + \text{PacketDelay}_w$$

The depreciation when using cellular network transmission is:

20

$$\text{Depreciation}_c = \text{PacketInterval} * N\text{Trans}_c + \text{PacketDelay}_c$$

When the appropriate network is used, the depreciation is the minimum of the above two cases:

25

$$\text{Depreciation} = \min(\text{Depreciation}_w, \text{Depreciation}_c)$$

The depreciation can be independently calculated for each pair of source and destination nodes. For a particular pair of source and destination nodes, when
 30 they are very close to each other, this will generally result in $N\text{Trans}_c > N\text{Trans}_w$ and $\text{PacketDelay}_c > \text{PacketDelay}_w$. In this case, it is clear that messages should be transmitted via the 802.11 network. On the other hand, when they are very far apart, this will generally result in $N\text{Trans}_c < N\text{Trans}_w$ and $\text{PacketDelay}_c < \text{PacketDelay}_w$, so cellular network is a better choice. Hence, there is a tradeoff that

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each sender needs to consider to decide which communication technology (802.11 or cellular network) is better. The values of p_{up} , p_{down} , and $p_{single,i,w}$ are estimated by the corresponding entities (either a vehicle or the GeoServer) in real time, and are propagated to those entities which need these values, as will be described in some more detail further below.

Generally, in vehicular communications, a message can have its destination characterized by a geographical area, number of hops, or dedicated receiving vehicle. According to embodiments of the invention, based on the relationship between $Depreciation_w$ and $Depreciation_c$ for all vehicles in a given *maximum* target area (corresponding to a particular vehicle as the sender), that area (also corresponding to the sender) is split into two different sub-areas:

- A 802.11 area (which contains vehicles for which $Depreciation_w < Depreciation_c$),
- A cellular area (which contains vehicles for which $Depreciation_w > Depreciation_c$).

The maximum target area is an area that contains all the possible target areas for different messages, corresponding to a specific vehicle as the sender. The corresponding situation is schematically illustrated in Fig. 2 for vehicle D from Fig. 1. The 802.11 area is the area in which the messages should be forwarded to with the 802.11 network (possibly using multi-hop transmission). Correspondingly, the cellular area is the area to which the messages should be forwarded via the cellular network (and pre-processed by the GeoServer). By this means, the depreciation of messages can be minimized.

It should be noted, that these areas are not necessary real geographical areas, but rather can be seen as a subset of vehicles, which can be reached either by 802.11 or cellular network. It should also be noted that there are different maximum target, 802.11, and cellular areas for different vehicles. However, although the specific areas for different vehicles are different, it does not necessarily mean that a large storage space is needed to store the areas for each vehicle. It is possible to

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specify the areas with some key factors on the shape and range of the region, with the respective vehicle as the center.

It is also noted that Fig. 2 is only used for the purpose of illustration and that there are many corner cases. For instance, if the maximum target area is small, there is no need to transmit the message over the cellular network and the 802.11 area can be the same as the maximum target area.

To ensure successful message transfer, there can be some overlap between the 802.11 and cellular areas, as can be seen also in Fig. 2. The size of the overlapping part depends on the uncertainty of the optimal area – the more uncertain the values of Depreciation_w and Depreciation_c are, the larger the overlapping part. On the other hand, however, a large overlap also increases the message redundancy, which could subsequently increase the information depreciation. Hence, an optimization algorithm that attempts to minimize the expected value of depreciation is used to determine the different areas.

Procedure for determining communication areas

According to the above discussion, the network selection algorithm essentially determines the 802.11 and cellular areas for each sender.

The cellular areas for all vehicles are specified by the GeoServer according to historical data (some data may be obtained via feedback from vehicles) regarding the information depreciation of both 802.11- and cellular-based transmissions. The 802.11 area is determined by each vehicle according to the control and feedback information from the GeoServer and its neighboring vehicles, as well as its own measurements on depreciation, link status, etc. A specific method for determining the 802.11 and cellular areas can be a fully centralized mechanism where the GeoServer determines both areas according to feedback information from vehicles, and transmits the result to each vehicle. In this case, the optimization algorithm at the vehicle only outputs the specification from the GeoServer. Another specific method can be a distributed mechanism for determining the 802.11 area, in which the GeoServer only transmits some necessary control information (such

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as the current cellular area) to each vehicle, and each vehicle determines the 802.11 area for itself. In both cases, the cellular area is determined by the GeoServer, because it has to process and forward all messages that are sent via the cellular network.

5

The determination of different areas also considers the delay in transmitting control and feedback information, particularly when the network topology has changed rapidly. In other words, the mechanism ensures that the entire maximum target area is always covered by either the 802.11 or cellular area. This can be achieved by adding a delay when shrinking an area, but by adding no delay when expanding an area. More explicitly, an area may be considered as a set of vehicles. The algorithm adds a vehicle into the area immediately when it finds it necessary according to the optimization algorithm, but it removes a vehicle from the area only after a delaying time, wherein the duration of this delay depends on the message transmission delay. For this purpose, the GeoServer maintains two cellular areas, one is obtained from the optimization algorithm (referred to as optimal area), and the other is the area used for actual transmission (referred as actual area). Similarly, each vehicle maintains these two 802.11 areas.

10
15
20 To sum up, according to one embodiment, as illustrated in Fig. 3, the algorithm contains the following entities:

1. At each vehicle: variables for storing its own (i.e. when it is the sender itself) actual 802.11 area, optimal 802.11 area, and actual cellular area (notified by the GeoServer). At the GeoServer: variables for storing the actual cellular areas, optimal cellular areas, optimal 802.11 areas when 802.11 areas (or a subset thereof) are determined by the GeoServer, and actual 802.11 areas (notified by each vehicle) for all vehicles (i.e. respectively when each of the vehicles is a sender).
- 25 2. A module for calculating the optimal areas based on historical data related to information depreciation
- 30 3. A set of timers, each of which stores a set of vehicles to be removed from the actual area at the specific time.
4. Other necessary modules, timers, variables, etc.

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The algorithm is run in a per-vehicle basis, i.e. each vehicle determines its own 802.11 area and the GeoServer determines the cellular area for each vehicle independently. Depending on the network condition, it is also possible that the
5 GeoServer determines both areas for each vehicle and forwards the result to the corresponding vehicle. The general procedure that is executed at each vehicle or for each vehicle at the GeoServer is shown in Fig. 3.

When a new message is received by a vehicle or by the GeoServer, respectively,
10 it leaves an idle state, indicated at (1), and runs the optimization algorithm based on received control and feedback information, as indicated at (2). At (3), the optimal areas are updated based on the results of the optimization algorithm. At (4), in case an actual area exists on the same entity, it adds vehicles that exist in the optimal area but do not exist in the actual area immediately into the actual
15 area, and it starts a delay timer for removing vehicles from the actual area. After delay timeout, it checks for each vehicle that should be removed if it exists in the current optimal area. If not, the vehicle is removed from the actual area, as indicated in (5). Alternatively, as shown at (5'), in case an actual area is on a different entity, it includes the resulting optimal area in the next packet sent to the
20 corresponding entity and returns to the idle state (1) afterwards.

It is noted that when the GeoServer determines both areas, step (2) in Fig. 3 becomes a dummy module at the vehicle side which only replicates the 802.11 area specified by the GeoServer. Also in this case, the GeoServer also calculates
25 the 802.11 area for each vehicle in (2) and stores them in (3), but it does not process the result of the optimal 802.11 area further, it sends the result in the next packet to the particular vehicle (5).

Given the different communication areas determined by the algorithm described
30 above, vehicles and the GeoServer can know which network to use when it has a message to transmit. When the scheduled time for sending a message has come, the sender (e.g., vehicle D in Fig. 1) checks whether the destination belongs to its 802.11 area or cellular area or both, and uses the corresponding network to transmit the message. Generally, vehicular application messages need to be

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broadcasted to multiple destinations which may or may not include the GeoServer. Hence, the sender needs to transmit the message to all networks corresponding to the areas that the destinations lie in. For example, in Fig. 1, if vehicle D wants to send a message to vehicles A, B, C, and E, it needs to send the message to the
 5 GeoServer (which forwards the message to A) via the cellular network and also broadcast the message via the 802.11 network, to ensure optimal information depreciation at each recipient. On the other hand, if D wants to send the message to B, C, and E or a subset of them, it only needs to broadcast this message via the 802.11 network, because they are all reachable and optimal via 802.11. If D wants
 10 to send the message to the GeoServer and/or vehicle A, it only needs to send the message via the cellular network.

The procedure can be summarized as the following pseudocode:

```

15  If scheduled time for packet transmission approached then
      Use_802.11←FALSE
      Use_Cellular←FALSE
      For each vehicle (may include the GeoServer) in the target area of the message
          If the vehicle is contained in the 802.11 area then Use_802.11←TRUE
20      If the vehicle is contained in the cellular area then Use_Cellular←TRUE
      End For
      If Use_802.11=TRUE then Send message via 802.11 network
      If Use_Cellular=TRUE then Send message via cellular network
  End If
25

```

Forwarding procedures

With respect to the forwarding of messages, a state transition diagram that can be applied at the vehicle side is illustrated in Fig. 4. According to this embodiment it is
 30 assumed that each vehicle stores a *reverse* 802.11 area. Unlike the original 802.11 area which specifies the area to which messages should be transmitted via the 802.11 network seen from the sender, the reverse 802.11 area considers the receiver side. The reverse 802.11 area at a particular vehicle (e.g. vehicle A in Fig. 1) includes those vehicles which have vehicle A in their original 802.11 area.

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By assuming reciprocal links, the reverse 802.11 area for a particular vehicle can be the same as its original (actual) 802.11 area, but this does not always need to be the case. A vehicle may obtain its reverse 802.11 area based on an operation on its original (actual) 802.11 area, together with some information regarding
5 802.11 areas of its neighboring vehicles.

According to the embodiment of Fig. 4, upon receiving a message via the 802.11 network from a sender (e.g. vehicle D in Fig. 1), each vehicle (i.e. vehicles C and E in Fig. 1) executes the following forwarding algorithm:

10

1. Each potential forwarder checks whether the sender (vehicle D in Fig. 1) belongs to its reverse 802.11 area.
2. Each potential forwarder checks whether it belongs to the target area of the message from the sender (vehicle D).
- 15 3. Each potential forwarder checks whether it has already received this message (either via 802.11 or cellular network).

If the answer to the above conditions 1. and 2. is "yes", the potential forwarder prepares to forward the received message to other vehicles in the target area. To
20 avoid causing broadcast storm, each potential forwarder waits for a randomly chosen interval. If, after the waiting period, this message is not forwarded during the chosen interval by another vehicle, and, meanwhile, the answer to the above condition 3. is "no", then the vehicle forwards the message. Condition 3. ensures that there is no redundant message being forwarded, because there may be some
25 overlap of the 802.11 area and the cellular area, and also because every vehicle in the 802.11 area of the sender is a potential forwarder.

Also, the area determination algorithm (as illustrated in Fig. 3) is always run first after receiving a message.

30

For the GeoServer the respective state transition diagram is illustrated in Fig. 5.

Upon receiving a message from a vehicle via the cellular network, the GeoServer checks whether there is an intersection between the target area of the message

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and the (actual) cellular area of the corresponding sender. If yes, the GeoServer processes this message, i.e. aggregates messages to the same destination if possible. The GeoServer may also wait for a time period before forwarding, to aggregate more messages or to balance the load. Then, it forwards the (possibly
5 aggregated) message to vehicles in the intersection of the target area and the (actual) cellular area, either using multicast/broadcast (eMBMS) or per multiple unicast messages (one unicast message per receiver).

Because the GeoServer builds a new message based on the message it has
10 received, it is not always necessary that the GeoServer sends the new message to each individual vehicle via the cellular network. It may choose one vehicle to receive the message via the cellular network. Then, this vehicle forwards the message to other vehicles in the intersection of the target area and the original (actual) cellular area (or a subset thereof) via the 802.11 network. The GeoServer
15 can make the judgment on which way it should send the messages based on feedback information from vehicles and based on its knowledge on the current optimal 802.11 area for each vehicle. The latter information may be included in packets sent to the GeoServer, as will be described in detail further below. The forwarding algorithm at the vehicle is the same as previously described in this
20 case, because the new target area is within the 802.11 area of the particular vehicle. Based on this information, the GeoServer can decide which way is the best for minimizing information depreciation.

25 Control/feedback information exchange and performance measurement

According to the embodiment illustrated in Fig. 6, the control and feedback information is sent together with the actual vehicular application messages. The 802.11 and cellular network transmissions coexist.

30 When packet intervals can be different between different vehicles

Because the depreciation is also related to the packet interval, which can be set to different values by the sender, only the delay and packet loss rates have to be estimated, from which the depreciation can be easily inferred.

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To assist the determination of the communication areas, each vehicle gathers the following information:

1. Delay and packet loss rate of packets received from the cellular network within a specific time window
- 5 2. Single-hop delay and packet loss rate of packets received from all its neighboring vehicles that are transmitted via 802.11 within a specific time window

The length of the time window is selected depending on the channel variation and the desired accuracy of estimation. A longer time window leads to higher
10 estimation accuracy but also increases the response time to channel variation, and vice versa. Each vehicle inserts the measurement results into packets that carry actual vehicular application information. To reduce additional communication overhead, it is possible that not all packets carry control and feedback information, i.e. control and feedback information is only attached to some of the packets.

15

Example of control and feedback information from each vehicle to the GeoServer can include the following:

1. Average delay of packets received from the cellular network
2. Standard deviation of the delay values of packets received from the cellular
20 network
3. Packet loss rate of packets received from the cellular network
4. Average delay of packets received from the 802.11 network from all neighboring vehicles
5. Standard deviation of the delay values of packets received from the 802.11
25 network from all neighboring vehicles
6. Average packet loss rate of packets received from the 802.11 network from all neighboring vehicles
7. Standard deviation of the packet loss rate values of packets received from the 802.11 network from all neighboring vehicles (i.e. one packet loss rate for each
30 vehicle, and compute the standard deviation for all packet loss rates)
8. The current optimal 802.11 area

- 20 -

The area may be specified by the indexes of some boundary vehicles. It is also important to note that vehicular applications generally include cooperative awareness, so that each vehicle knows the locations of its neighboring vehicles.

- 5 Upon receiving the information, and also performing similar estimation at the GeoServer side, the GeoServer can estimate the depreciation of different networks using aforementioned formulas. The values of $p_{m,w}$ can be estimated by averaging over possible paths along which the packet may be forwarded. The standard deviation values are used to indicate the variation of the estimated
- 10 values and can be used to determine how large the overlapping area should be.

Example of control and feedback information sent or pushed from the GeoServer to each vehicle can include the following:

1. Suggested optimal 802.11 area based on data at the GeoServer
- 15 2. The current optimal cellular area

The suggested optimal 802.11 area does not need to be the true optimal 802.11 area. Each vehicle may modify this area based on its most recent measurements etc. However, the majority work on determination of the 802.11 area is done on

20 the GeoServer in this case.

When packet intervals of all vehicles in a particular area is fixed

In this case, it is possible to directly measure the depreciation. For the 802.11

25 network, it is also possible to measure the depreciation from all senders (not just the neighboring nodes). Then, the amount of information to be exchanged can be reduced.

The control and feedback information from each vehicle to the GeoServer can

30 include the following:

1. Average depreciation of packets received from the cellular network (downlink)
2. Standard deviation of the depreciation values of packets received from the cellular network (downlink)

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3. Average depreciation of packets received from the 802.11 network from vehicles with the maximum number of hops
4. Standard deviation of the depreciation values of packets received from 802.11 network from vehicles with the maximum number of hops
- 5 5. The current optimal 802.11 area

Control and feedback information from the GeoServer to each vehicle can include the following:

1. Average depreciation of packets received from the cellular network (uplink)
- 10 2. Standard deviation of the depreciation values of packets received from the cellular network (uplink)
3. The current optimal cellular area

15 In this case, each vehicle has the most information, and can determine its own 802.11 area.

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
20 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.

25

Claims

1. Method for transmitting messages by nodes in a vehicular ad-hoc network (VANET),
5 wherein the nodes are equipped with first communication means for operating via a cellular network – cellular transmissions – and with second communication means for operating via wireless local area network (WLAN) channels – 802.11 transmissions –, and
 wherein said vehicular ad-hoc network includes a central entity that serves
10 as a message reflector to enable cellular-based communication among the nodes of said vehicular ad-hoc network,
 c h a r a c t e r i z e d i n that a node dynamically selects the network to use for transmitting messages, wherein said network selection is performed in such a way that a predefined performance metric is optimized.
15
2. Method according to claim 1, wherein said performance metric is selected from a group of performance metrics including information depreciation, message delay and packet loss.
- 20 3. Method according to claim 1 or 2, wherein a node calculates or estimates said performance metric independently for each destination node.
4. Method according to any of claims 1 to 3, wherein a maximum target area of a node is divided into two communication areas, including a cellular area, which
25 contains receiving nodes for which cellular transmissions outperform 802.11 transmissions in terms of said predefined performance metric, and a 802.11 area, which contains receiving nodes for which 802.11 transmissions outperform cellular transmissions in terms of said predefined performance metric.
- 30 5. Method according to any of claims 1 to 4, wherein the nodes and said central entity, upon receiving a new message, estimate said predefined performance metric based on available control and feedback information, both with respect to cellular transmissions and with respect to 802.11 transmissions, and perform an optimization process both for the cellular area and the 802.11 area.

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6. Method according to claim 4 or 5, wherein a centralized mechanism is applied in which the cellular area and the 802.11 area are determined by said central entity.
- 5
7. Method according to any of claims 4 to 6, wherein said central entity determines the cellular area and the 802.11 area based on historical data regarding said predefined performance metric.
- 10
8. Method according to claim 7, wherein said historical data includes information said central entity obtains via feedback from the nodes of said vehicular ad-hoc network.
9. Method according to claim 4 or 5, wherein a distributed mechanism is applied in which the 802.11 area is determined by each node for itself based on control and feedback information the respective node receives from said central entity and/or from its neighboring nodes.
- 15
10. Method according to any of claims 6 to 9, wherein said centralized mechanism and said distributed mechanisms are adaptively selected according to the current network conditions.
- 20
11. Method according to any of claims 4 to 10, wherein the cellular area and the 802.11 area are generated in such a way that they have an overlapping part with each other.
- 25
12. Method according to any of claims 1 to 11, wherein the nodes gather information on delay and packet loss rates of packets received from the cellular network within a specific time window.
- 30
13. Method according to any of claims 1 to 12, wherein the nodes gather information on single-hop delay and packet loss rates of packets received from all respective neighboring nodes transmitted via the 802.11 network within a specific time window.

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14. Method according to claim 12 or 13, wherein the length of the time window is selected depending on the channel variation and the desired accuracy of estimation.
- 5
15. Method according to any of claims 12 to 14, wherein the nodes inserts said gathered information into regular packets as control and feedback information.
16. Method according to any of claims 4 to 15, wherein a suggested expansion of a communication area resulting from the optimization process is implemented by the respective node immediately.
- 10
17. Method according to any of claims 4 to 16, wherein a suggested diminution of a communication area resulting from the optimization process is implemented by the respective node with a delay of configurable duration.
- 15
18. Method according to any of claims 4 to 17, wherein said central entity maintains for each node a first cellular area that is obtained from the optimization process – optimal cellular area – and a second cellular area – actual cellular area – used for actual transmissions.
- 20
19. Method according to any of claims 4 to 18, wherein each node maintains a first 802.11 area that is obtained from the optimization process – optimal 802.11 area – and a second 802.11 area – actual 802.11 area – used for actual transmissions.
- 25
20. Method according to any of claims 4 to 19, wherein each node stores a reverse 802.11 area that includes those nodes which have the respective node in their actual 802.11 area.
- 30
21. Method according to claim 20, wherein a node executes a forwarding algorithm including the steps of
- checking whether the sender of a received message belongs to its reverse 802.11 area,

- 25 -

checking whether it belongs to the target area of the message received from the sender, and

forwarding the received message after a time interval in case both checks yield positive results and the node has not yet received the message beforehand.

5

22. Method according to any of claims 4 to 21, wherein said central entity, upon receiving a message from a node via said cellular network, executes a forwarding algorithm including the steps of

10 checking whether there is an intersection between the target area of the received message and the actual cellular area of the respective sender of the message, and

in case the check yields a positive result, forwarding the received message after a time interval to nodes within said intersection either using multicast/broadcast messages or per multiple unicast messages.

15

23. Method according to claim 22, wherein said central entity select one node within said intersection to receive the messages via said cellular network, wherein the selected node then forwards the messages to the other nodes within said intersection via said 802.11 network.

20

24. Method according to any of claims 1 to 23, wherein said central entity is a GeoServer.

25. Node for deployment in a vehicular ad-hoc network (VANET), in particular for executing a method according to any of claims 1 to 24,

25

the node being equipped with first communication means for operating via a cellular network – cellular transmissions – and with second communication means for operating via wireless local area network (WLAN) channels – 802.11 transmissions –,

30

wherein said vehicular ad-hoc network includes a central entity that serves as a message reflector to enable said cellular-based communication of the node with other nodes of said vehicular ad-hoc network,

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c h a r a c t e r i z e d i n that the node is configured to perform dynamic selection of the network to use for transmitting messages in such a way that a predefined performance metric is optimized.

- 5 26. GeoServer, being configured to execute a method according to any of claims 1 to 24.

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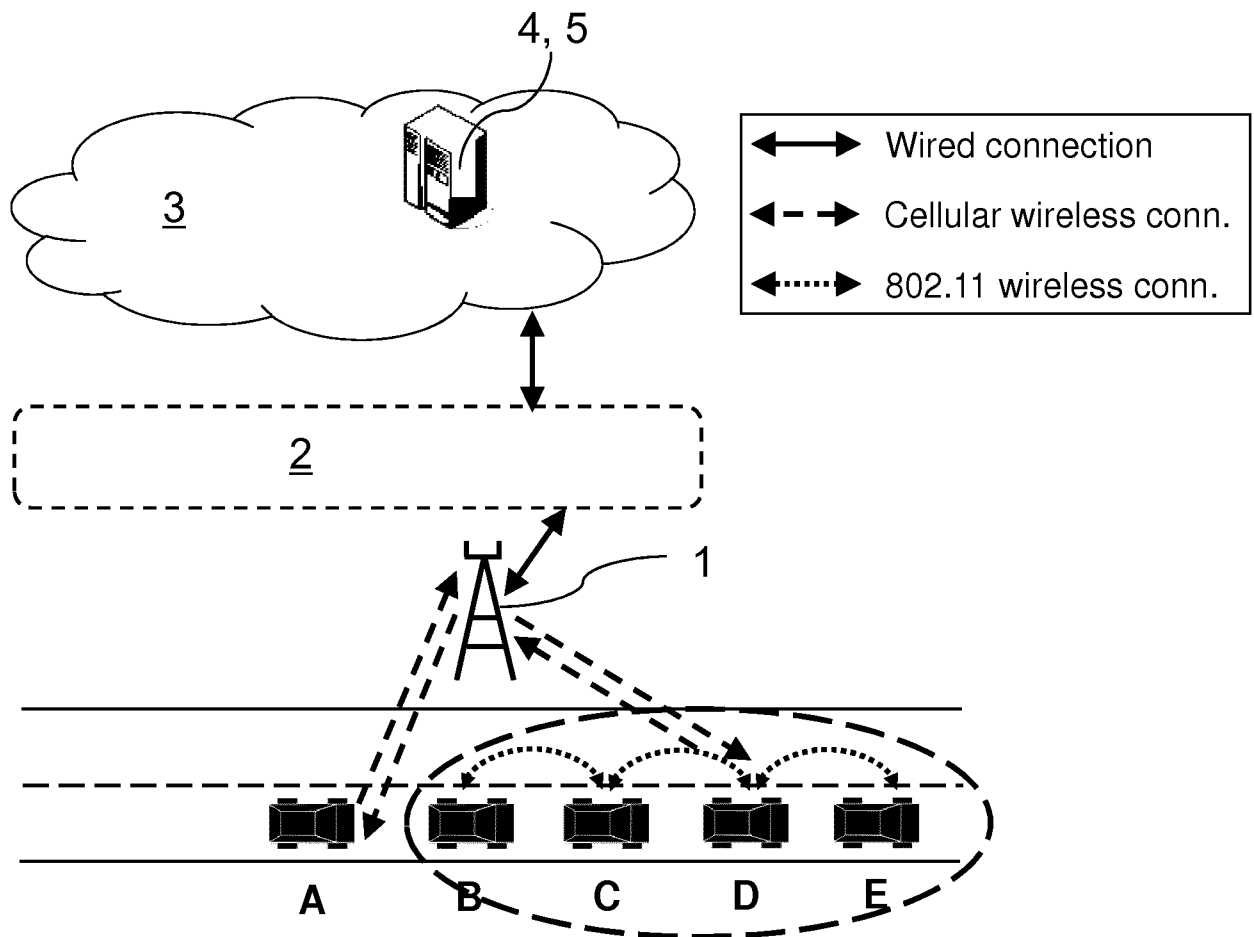


Fig. 1

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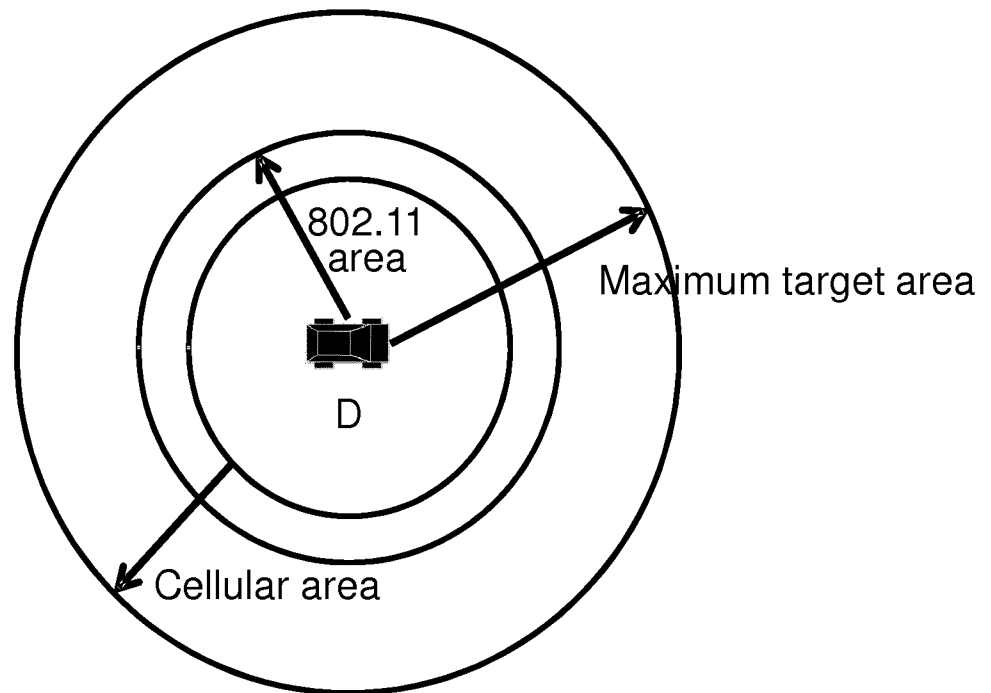


Fig. 2

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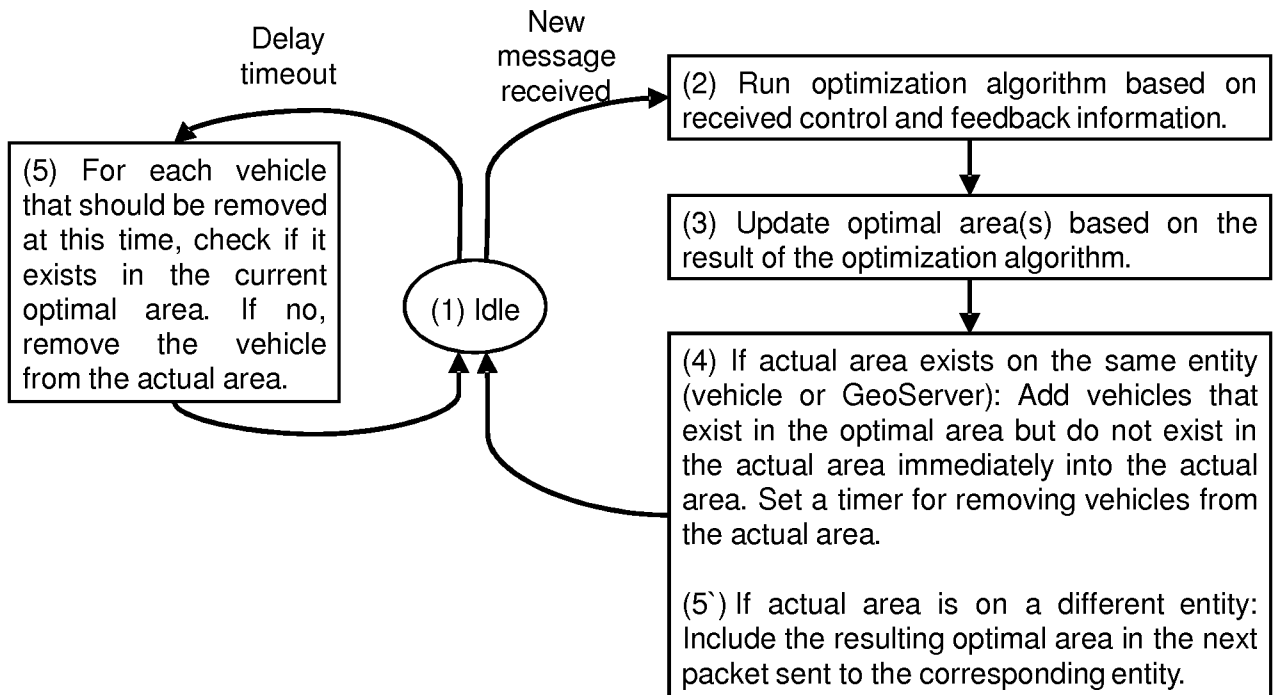


Fig. 3

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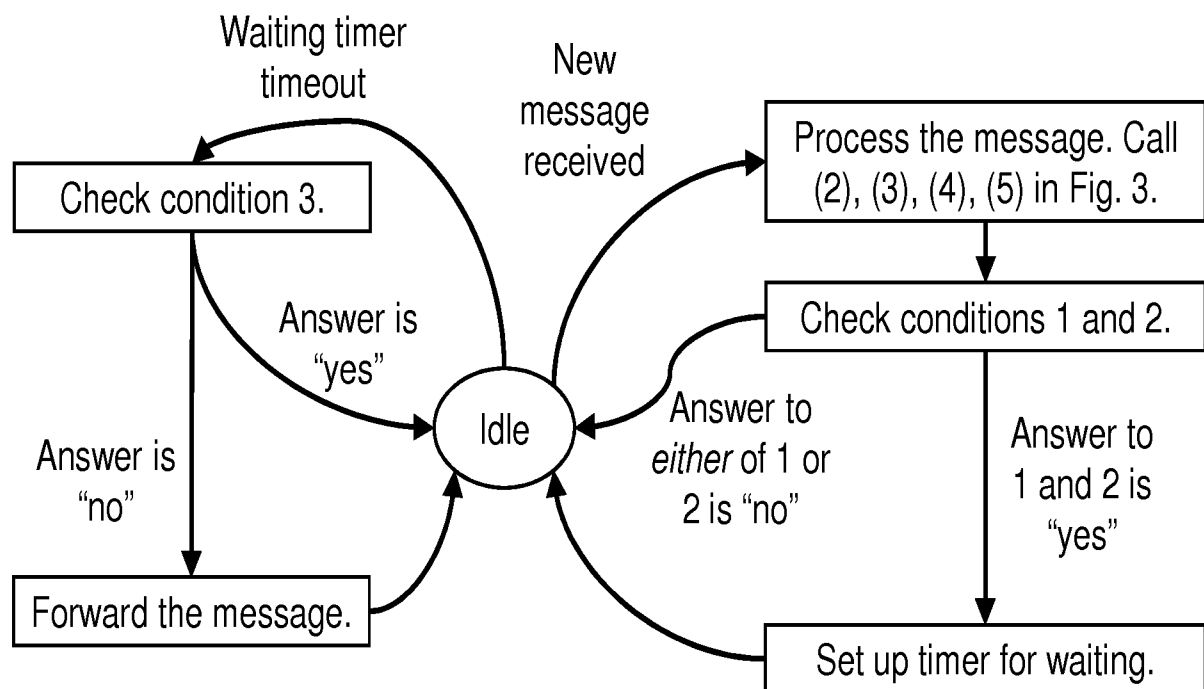


Fig. 4

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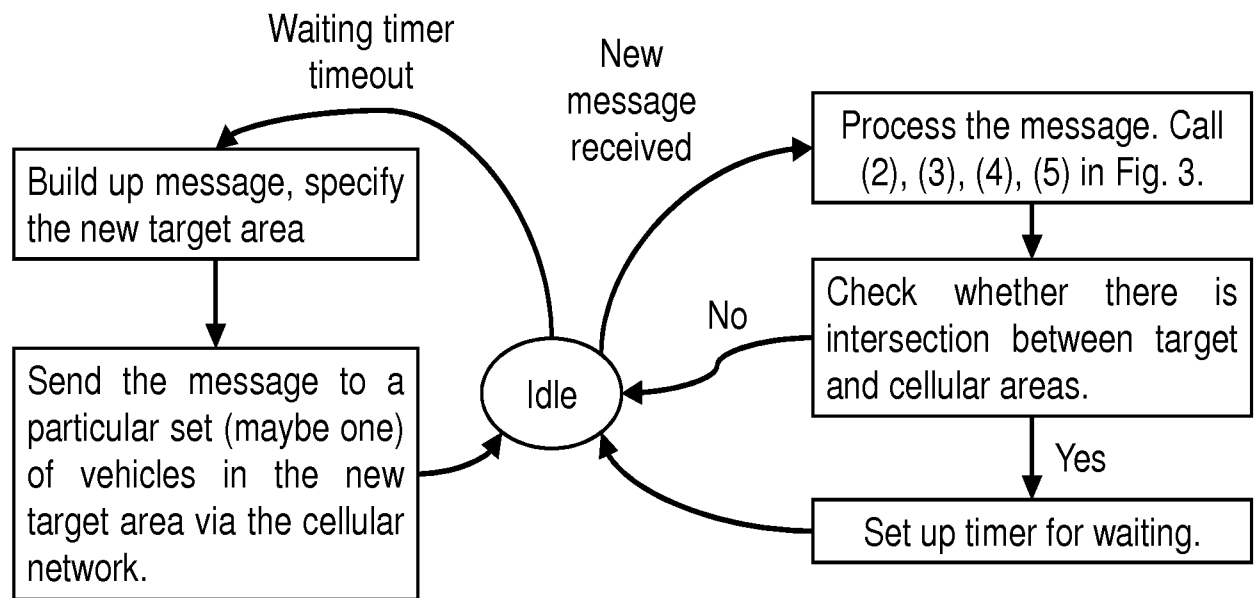


Fig. 5

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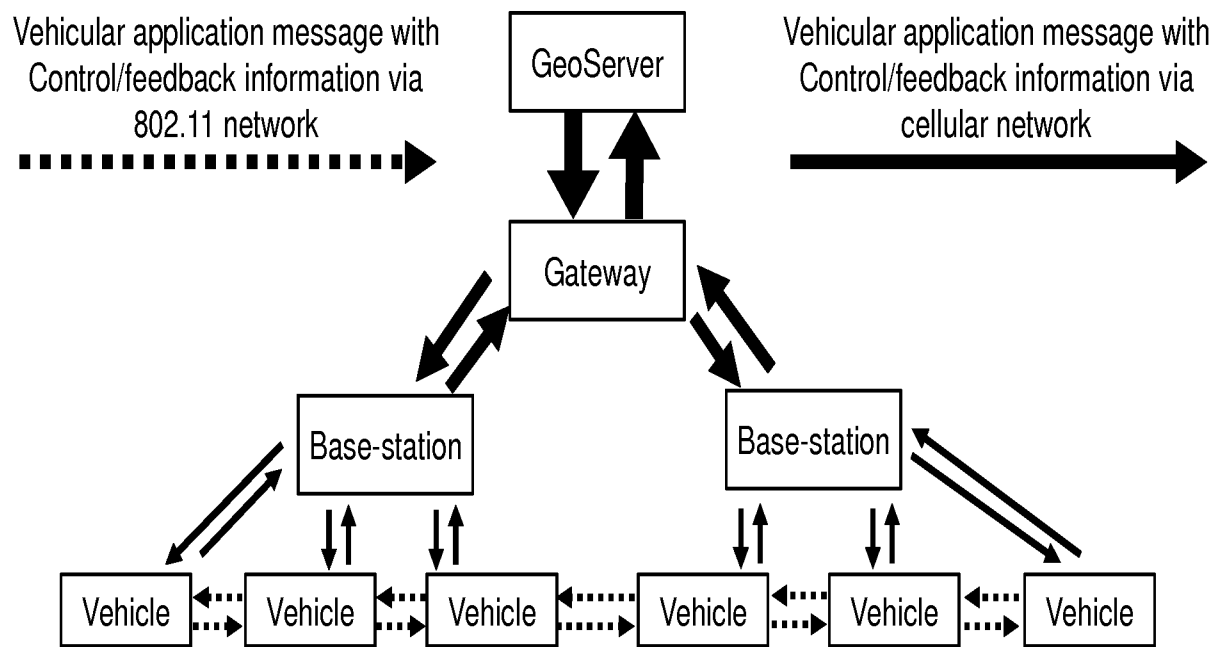


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/070578

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W4/04 H04W48/18
ADD.

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

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, COMPENDEX, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	US 2013/238807 A1 (WAKIKAWA RYUJI [US] ET AL) 12 September 2013 (2013-09-12) paragraph [0003] - paragraph [0005] paragraph [0025] - paragraph [0107] -----	1-26
X	US 8 514 825 B1 (ADDEPALLI SATEESH K [US] ET AL) 20 August 2013 (2013-08-20) column 11, line 35 - column 18, line 47 column 28, line 24 - column 35, line 54; figures 2, 3A, 3B -----	1-26
A	WO 2013/090317 A1 (MOTOROLA SOLUTIONS INC [US]) 20 June 2013 (2013-06-20) the whole document -----	1-26
A	US 2008/089298 A1 (ANSCHUTZ THOMAS ARNOLD [US] ET AL) 17 April 2008 (2008-04-17) the whole document -----	1-26



Further documents are listed in the continuation of Box C.



See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

28 May 2014

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2013/070578

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