Survey on context-aware publish/subscribe systems for VANET

Mickaël Royer, Alain Pirovano, Fabien Garcia

Survey on Context-Aware Publish/Subscribe systems for VANET

Mickaël Royer, Alain Pirovano, Fabien Garcia

ENAC - French Civil Aviation University

Abstract. The publish / subscribe scheme is an efficient paradigm for communication widely used in wired networks. However the use of this paradigm in the context of mobile networks such as VANETs is still an open research topic. In particular, the communication needs of mobile nodes often depend on the node state, location and/or surroundings. Consequently, extensions to the P/S paradigm have been proposed that introduce the concept of *node context*. This paper propose a survey on these context-aware publish / subscribe solutions for VANETs. We will particularly focus our discussion on two example applications drawn from the context of civil aviation and will argue that Aeronautical Ad hoc Networks (AANETs) are a subgroup of VANETs.

Keywords: Vehicular Ad Hoc Network (VANET), Aeronautical Ad Hoc Network (AANET), Publish / Subscribe communication systems.

1 Introduction

Publish/Subscribe scheme is a communication paradigm which differs in many ways from classical communication schemes where addresses are used to identify the recipients. These addresses can target a single receiver (unicast communication) or multiple receivers (multicast communication). On the contrary, Publish/Subscribe systems allow *event* distribution from *publisher* (event producer) to *subscriber* (event consumer) without the use of any explicit address. Instead, the event distribution is based on declared subscribers interests. Those interests can be expressed in different ways depending on the subscription model used.

In the *topic based* subscription model, clients subscribe to topics characterized by a name. Events are then published on topics and the P/S system is responsible for the forwarding of events to clients who subscribed to this topic. The topic based subscription is quite simple but it's also limited since we can only filter events from a single attribute, i.e.: the topic name.

On the other side, in the *content based* subscription model, clients base their subscriptions on the content of events. So, when an event is published, the P/S system has to forward it to the clients whose subscriptions match the event content. The filter syntax "attribute – operator – pattern" can be used to define this subscription as described in [1].

For example, persons holding stock of a company are generally interested in the evolution of its price. With to a topic based P/S system, we can easily think of a solution where these clients subscribe to a `'stock topic'` and receive notifications each time the price of the stock has changed. With the use of a content based P/S system, we can be much more efficient in filtering events. For example, a subscription can allow to receive notification only when price pass through a threshold.

P/S systems offer many advantages over traditional communication. In particular, they offer communications decoupled in space (subscribers do not need to know publishers and vice-versa) and potentially in time if the P/S system is able to store events for clients which are temporally disconnected (as in delay tolerant networks [2]).

In the past decade, many solutions (see for example [3] and [4]) have been proposed by the research community and industrials to build P/S system over wired networks. However, as emphasized in [5], those solutions are ill-adapted to the emerging category of networks called Mobile Ad hoc Networks (MANET). MANETs are defined as self-configuring networks of mobile nodes connected by wireless links without fixed infrastructure. In this category of networks, one sub-category will be dealt with in this paper, the Vehicular Ad hoc Networks (VANET) whose nodes are vehicles. In both MANETs and VANETs, disconnections between nodes are a common occurrence and the wired network centred solutions for P/S systems are not likely to take handle them satisfactorily. Accordingly, new solutions have been proposed to offer P/S communication systems optimized for VANET. The aim of this article is to provide a survey of these solutions.

This paper is organized as follow, in section 2 we present important characteristics of a VANET and argue that AANET (Aeronautical Ad hoc Networks, i.e.: VANETs composed of aircraft) are a subgroup of VANETs. In section 3, we illustrate possible applications of P/S systems over VANETs. We then use those applications to present the expected features of P/S systems for VANETs and the main challenges associated to their definition in section 4. Finally, we describe existing solutions of P/S systems adapted to VANET and evaluate their suitability to our purpose and constraints in section 5, before concluding this paper in section 6.

2 VANETs characteristics and AANETs

A VANET can be defined as a self-organizing communication network composed of mobile vehicles using wireless communication links. VANETs are a subcategory of MANETs with some specificities. The most important is the high mobility of their nodes which leads to more frequent partitioning of the network [6]. Although, VANETs are associated most of the time to car, we argue in this section that other vehicle types can be used, like civil aircraft for example.

Indeed, lately, new communication means are studied to fulfil airlines and passenger communication requirements. In this context, AANETs (Aeronautical

Ad hoc NETworks, i.e.: MANETs with aircraft as nodes) represent an attractive solution. The feasibility of such networks has been demonstrated for instance in [7]. This category of network can be seen as a subcategory of VANETs as emphasised in [8]: "MANETs that span planes, trains, automobiles, and robots are called vehicle ad hoc networks (VANETs)". As illustrated in table 1, we list the main characteristics of VANETs based on descriptions found in related articles and show that AANETs share most of the characteristics of VANETs with cars. Some characteristics of AANET are obvious like *high mobility of nodes* or *high probability of network partition*. Some others need more explanation. In the same way as cars have movements constrained by road and traffic, civil aircraft have to follow trajectory imposed by air traffic controller. Furthermore, AANETs can also be subject to channel congestion problem. Indeed, some area, like close to airports, can have a hight density of aircraft, which may cause interference problem as explained in [9].

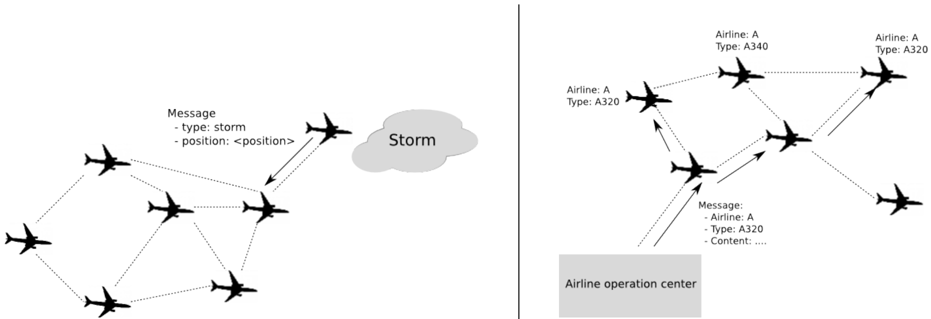
VANET Characteristics	Ref	Relevant for AANET
High mobility of nodes	[6], [10], [11], [12], [13]	Yes
High probability of network partition	[6], [10], [12]	Yes
Predictability of the movements of nodes	[6], [11], [12], [13]	Yes
Very large scale	[6]	Yes
Velocity restricted by speed limits and road traffic	[11]	No
Channel congestion risk due to a high vehicular traffic density	[14]	Yes
No energy restriction	[11], [12]	Yes
Type of application : geographical, hard delay constraint	[12]	(Yes)
Interaction with on-board sensors	[12]	Yes

Table 1: VANET / AANET characteristics comparison

As we will see in the next section, many applications of the P/S communication paradigm can be applied to AANETs, especially for the ATC (Air Traffic Control) or AOC (Airline Operational Communication) domains. This is the reason why this specific subgroup of VANETs has been targeted in the examples introduced in the next section. However, these examples can be easily transposed to VANETs with car (ex: cab company communication toward all of their cabs or announcement of a car accident)

3 Application examples in AANET

To better understand the specific needs of AANET Publish / Subscribe applications, this section introduces two such example applications in the context of civil aviation. The first example is the dissemination of weather situation update to aircraft located at a specific geographic area. The second example is the dissemination of content to all aircraft of an airline company.



(a) An aircraft sends a message about a dangerous storm

(b) an airline sends a message to a part of its fleet

Fig. 1: Example of P/S applications in AANETs

3.1 Weather situation update

For safety reasons, weather informations are crucial during a flight. Some phenomena like storm or wind shear are very dangerous for aircraft and so must be transmitted from ground weather stations or from an aircraft discovering a new situation to all aircraft that might encounter it. Today, most of these communications, in particular in oceanic area, use satellite links which are more expensive than classical air-group communication infrastructure like VDL (VHF Data Link) or HFDL (HF Data Link) network, as illustrated in [15].

A new solution for those communications can be found with the use of a P/S system over an AANET composed of commercial aircraft and ground stations. In this case, publishers would be weather stations or aircraft which have knowledge about dangerous weather situations and subscribers would be aircraft which whose trajectory will get close to the concerned geographical area during the period of the weather phenomena. In order to cover this communication need, events must contain at least the following attributes: type of phenomenon, geographic area of weather phenomena and lifetime (since the weather informations are necessarily associated to a time period).

Similarly, in order to subscribe an aircraft need to know its geographical position (for example with a GPS receiver) and, if possible, its short term trajectory. Indeed, an aircraft will be only interested in weather information near its actual or short term position. A subscription will consequently follow the following principle : "I want to receive all weather informations regarding the geographical area `<position>` which will happen in the time period `<time>` (deduced from current position and trajectory)."

Consequently, as illustrated in figure 1a, an event will be disseminated to subscribers located near the geographical area of the event, or converging to that point in the near future.

3.2 Message to all aircraft of an airline

Another important class of communication in civil aviation consists in the communication between airlines operational center and their aircraft (this type of communication is called Airline Operational Communication or AOC). During a flight, many informations must be exchanged between these two actors (e.g.: maintenance information, crew communications, etc.). Nowadays, this kind of communication mainly uses ACARS (Aircraft Communication Addressing and Reporting System). ACARS is a network deployed in the 80s by airlines to allow data communication with their aircraft. Depending on the aircraft position, it can use VDL (VHF Data Link) network or SATCOM means. Although robust, this network has very limited resources (bandwidth in the amount of tens of Kbits/s, [16]).

As in the previous example, a new solution can be proposed with the use of a P/S system over an AANET (which offers better performance than ACARS, as explained in [7]) composed of aircraft and airline operational center. In this example, as illustrated in figure 1b, publishers will be airline operational center and subscribers will be aircraft. To be properly filtered, events and subscriptions must contain at least the airline name as attribute. Furthermore, the advantage of a P/S system over a classical multicast communication would be in the filtering capabilities it offers. Indeed, more focused communications can easily be achieved with events being transmitted only to a specific type of aircraft or to aircraft bound for a given airport.

4 Expected features of P/S systems for VANET

The examples of the previous section show that traditional P/S system can not provide an optimal answer to the VANET content-based communication research question. In the first example, with a classical P/S solution, planes can subscribe to `'dangerous weather situation'`. However, this subscription will be too large and will lead to the reception of useless events since planes are interested specifically by `'dangerous weather situation` *`close to their position or route`* `'`. To accommodate this kind of subscription, a new concept is needed: the *node context*. Furthermore, one of the VANETs features is the high probability of network partitioning leading to frequent disconnections. A consequence of these disconnections is that some events (potentially critical) will not be received. To avoid this situation, a P/S system designed for VANETs needs to allow *the persistence of events in the network*. These two features are detailed in this section.

4.1 Node context

A node context is a list of attributes which complements subscriptions, and is used to more precisely filter received events. This better filtering allows a reduction in the use of network resources which are scarce in VANETs. Several definitions exist for node context. Simple definitions reduce context to the node location ("location context", see [17], [18] or [19]). Some other definitions like [20] are more generic and define the node context has a combination of static attributes and dynamic attributes, either defined in an absolute way or defined in relation with other nodes. For example, the velocity of a node can be considered as a dynamic context attribute. An absolute definition of this attribute will be `'velocity = 50 mph'` while a relative definition will be `'velocity superior to the velocity of the node in front of me'`. In relation to the examples discussed above, a node context would be defined as the node location, changing over time. We think that static attributes are not mandatory as they can easily be included in the subscriptions. For the second example introduced above, the company name of an aircraft can be seen as a static context attribute. In a content-based P/S system, this context attribute could easily be replaced by an `'airline name'` attribute correctly filled in subscriptions and published events.

Node context should not be mandatory to dispatch events. Indeed, in the example in section 3.2 the node location is not relevant for the communication (i.e.: an airline want to send a message to all aircraft, regardless of their position).

4.2 Persistent events

As explain in [21], the persistence of events is the ability for a P/S system to store events during its lifetime. Thus, subscribers interested by an event but not connected when this event has been sent are able to retrieve it later.

Traditional P/S systems for fixed infrastructure network do not necessarily implement this feature. However, this feature is essential for VANETs where disconnections of node are frequent. To save network resources, the persistence can be handled with the introduction of a lifetime associated to each event. Indeed, most of the time, an event is of interest only for a given time period and can be deleted afterwards. Some solutions, like[20], also use a lifetime associated to each subscription. We do not think this is mandatory since P/S API generally include an UNSUBSCRIBE primitive to remove a subscription from the system. To add persistence to a P/S system, two family of solutions exist. Events can be retransmitted periodically by publishers, this is costly in network bandwidth though, especially for a VANET. Another solution would be to store events in the network during its lifetime. Events can be hold by publishers (the simplest way) or by any node in the network (such as a broker for a P/S system based on overlay network, see next section).

5 Existing solutions

Recently, technical solutions have been proposed to offer Publish/Subscribe communication systems adapted to VANETs. They can be classified in three categories: geographic routing based solutions, proximity routing based solutions and overlay network based solutions. In this section, the technical principles are detailed for each of these groups of solutions. Advantages and disadvantages are then identified, particularly in the light of the expected features of a P/S systems detailed in the previous section (node context and persistence of events). The two AANET based applications introduced in section 3 will be used as illustrations. Figure 2 show the situation considered, which includes two communications from a same publisher. The first communication correspond to a weather situation update sent toward a geographical area where 4 planes are present. The second communication is a message sent to all plane of an airline (grey planes in the figure).

Fig. 2: Communication example in an AANET

5.1 Geographic routing based solutions

The solutions presented in this section use geographic routing to dispatch events from the publisher to the subscribers. In order for those to work correctly, two conditions must be met: network nodes must be equipped with a positioning system (e.g.: a GPS receiver) and all events must be associated with a geographical area. Many examples of applications respecting these assumptions can be introduced, starting with the example from section 3.1.

PCBD Persistent Content-Based Dissemination [22] is a solution that was defined for VANETs composed of both cars and info-stations (i.e.: fixed infrastructure nodes). This solution uses the following mechanisms: first, the publisher sends an event to a geographical area using a geographical routing protocol, this event is received by all nodes (cars and info-stations alike) in the area; then this event is stored in an info-station if there is one available, or else in vehicles. To choose the most appropriate vehicles, navigation systems can be used to determine the vehicles that will remain for the longest time in the area. Each vehicle periodically advertises its planned route and its interests (classical subscription mechanism, with in addition a vehicle context, the planned route). Info-stations or vehicles receiving subscriptions try to match them with their stored events. Events with positive matching are then sent to the corresponding subscriber.

Context-Aware PS for MANET As for PCBD, this solution, introduced in [20], uses a geographical routing protocol in order to disseminate an event in the geographical area associated. There are, however, two significant differences. First, the notion of context is explicitly defined and the classical publish / subscribe API has been extended to use it efficiently. Secondly, nodes interested by events for a specific zone do not have to wait to be in the target area to send their subscription request since they also use a geographical routing protocol.

Application example As illustrated in figure 3, geographic routing based solutions fit well with applications where subscribers are grouped in an area, but they are not adapted to case where subscribers are dispersed in the network. In this last case it would equivalent to broadcast the message since the target geographical area covers the entire network.

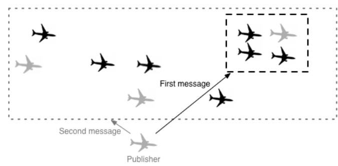


Fig. 3: Application example with Geographic routing based solution

5.2 Proximity routing based solutions

Solutions detailed in this section use the idea that most nodes interested by an event are close to the publisher. From this assumption, events are broadcast within a restricted geographical range around the publisher.

STEAM Scalable Timed Events And Mobility, presented in [18], is a content based publish/subscribe system designed for Wireless Ad-Hoc Network. In order to achieve scalability, this solution introduce the concept of proximity filters in addition to topic and content filters. This new filter introduces a range of dissemination around the publisher for the events. Each event is then sent only to nodes within this range of the publisher. This is motivated by the applications envisioned for this system (e.g.: a traffic light application where traffic lights produce events to indicate light changes to vehicle near them) and by the need to achieve good scalability on Ad Hoc networks with limited resources.

PERHAVO/LPSS Location-based Publish-Subscribe Service, defined in [23], uses the notion of proximity to disseminate events and subscription to a geographical range around the publisher and the subscriber respectively. To match a publication to a subscription one has to meet two conditions : the content match (as for any other content based P/S system) and the location match (i.e.: the subscriber and the publisher must both be located in the intersection of the publication and subscription spaces).

ALPS Adaptive Location-based Publish/Subscribe [19] is a location-based Publish/Subscribe solution. As LPSS, this solution includes a notion of location context complementing content-based queries. This context is then used to complement the content match with a location match. There are two main differences with LPSS. First ALPS introduces three content match strategies: "(1) message-centric algorithms (MCAs), where publishers broadcast messages in the message range and subscribers are in charge of performing matches; (2) query-centric algorithms (QCAs), where subscribers broadcast queries in the query space and publishers perform matches and subsequently route messages; and (3) hybrid ones (Hybrid) where both messages and queries are broadcast within a restricted area. In this last strategy, intermediate nodes are in charge of performing matches and routing messages to subscribers." In this terminology, LPSS uses only message-centric algorithm. The second difference with LPSS is that ALPS offers persistence of messages in the network thanks to the introduction of a lifetime specified by the application for each event. To ensure this persistence, events are retransmitted periodically by publishers.

Application example All the solutions detailed in this section introduce and use the location context of node to dispatch an event. Some of them (like ALPS) also implements persistent messages, which is a critical feature for a P/S system adapted to VANET as discussed in section 4.2. However, as illustrated in figure 4, proximity routing based solutions, although they have the advantage of not using many network resources, are only suitable for cases where publishers and subscribers are close together. Consequently, this kind of solutions cannot be used for the applications introduced in section 3.

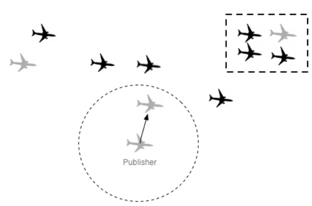


Fig. 4: Application example with Proximity routing based solution

5.3 Solutions based on overlay network

The solutions that will be discussed in this section introduce a new component in the P/S architecture: the *broker*. Brokers are the entities responsible for dispatching events from publishers to subscribers and are interconnected thus forming an overlay network.

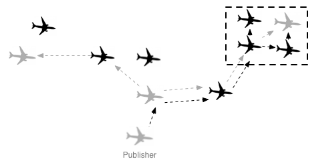


Fig. 5: Application example with solutions based on overlay network

Most P/S middleware for wired-networks are overlay network based solutions ([3], [4]). Accordingly, some P/S systems try to adapt this concept in the context of MANETs. They are detailed in this section.

REDS / SPCF REconfigurable Dispatching System [24] is a content based P/S framework adapted to mobile network topologies like those of VANETs. REDS is a modular solution which offers several protocol implementations to dispatch event and manage dynamic broker topology (as in [25]). In particular, REDS offers an implementation for a context-aware P/S system with the SPCF (Shortest Path Context Forwarding) protocol [26]. This solution introduces a new API to manage node context in subscriptions and publications. This context information is used in the routing process in the overlay network, with the introduction of a context table for each broker. SPCF uses this table with the more classical content table to make forwarding decisions in the broker network.

REBECA Rebeca Event-Based Electronic Commerce Architecture [27] is another content Publish/Subscribe system based on a modular framework. Unlike REDS, REBECA has been primarily developed for fixed networks. An extension of REBECA as then been proposed in [28] to support mobility. This extension introduces the concept of logical and physical mobility for clients. Physical mobility results in the disconnection of a client from his broker and the connection to another broker. This phase can produce a loss of events and so has to be handled correctly by the P/S System. Logical mobility happens when a client moves without broker disconnection. In this case, the client may need to update its subscriptions (called "automated location awareness within a defined environment" in the article). Logical mobility can be seen as a restrictive context used to update a subscription. The mobility extension of REBECA proposes solutions to deal with these two mobility issues by using two features of REBECA: the publisher advertisement [21] and the routing algorithm based on "Learning by the Reverse Path" [29].

Application example As illustrated in figure 5 (where all *visible* nodes are considered to be brokers), solutions based on overlay network are suitable for the two application examples introduced in the section 3. However, the main disadvantage of these solutions is that significant network resources consumption goes toward maintaining the overlay network.

Solution families		Geographic routing based solutions		Proximity routing based solutions			Overlay network based solutions	
Solutions		PCBD	Context-Aware PS for MANET	STEAM	LPSS	ALPS	REDS/SPCF	REBECCA
Network Characteristics	With infrastructure		X					X
	Without infrastructure	X	X	X	X	X	X	
Features	location context aware	X	X	X	X	X	X	X
	persistent events	X	X			X		X
Distribution of recipients	Located in a limited area	X	X	X	X	X	X	X
	Dispatched in all the network						X	X

Table 2: Solution synthesis

5.4 Synthesis

Table 2 provides a synthesis of P/S solutions according to several criteria: adaptability according VANET characteristics or distribution of recipients and available features for applications.

6 Conclusion

In this article, we have performed a survey on current solutions for publish / subscribe systems in VANETs. We first presented the main characteristics of VANETs, and argued that Aeronautical Ad Hoc Networks were a subgroup of VANETs. We then presented two examples of application of a publish/subscribe system in the particular context of AANETs in civil aviation, stating that similar applications could be found in the more general context of the VANETs. Using these two applications, we have extracted two desirable features of P/S systems for VANETs, namely the node context filtering and the persistence of events in the network. Finally, we presented three classes of solutions for P/S systems in VANETs, geographic routing based solutions, proximity based solutions and overlay network based solutions. As we emphasized in each case, none of these solutions can tackle all the communication needs of the two example applications. Geographic routing and proximity routing based solutions are ill-adapted to the case where subscribers are disseminated throughout the network. To this regard overlay network based solutions seem the best suited, but the amount of overhead introduced by the maintenance of the overlay network might be a problem in resources limited VANETs.

A comprehensive evaluation of the existing solutions through simulations and the development of a specifically designed P/S system able to address the underlined limits shall then be our next step toward the definition of a scalable, flexible P/S system for VANETs.

References

1. Marcos K. Aguilera, Robert E. Strom, Daniel C. Sturman, Mark Astley, and Tushar D. Chandra. Matching events in a content-based subscription system. In

Proceedings of the eighteenth annual ACM symposium on Principles of distributed computing, PODC '99, pages 53–61, New York, NY, USA, 1999. ACM.

2. Zhensheng Zhang. Routing in intermittently connected mobile ad hoc networks and delay tolerant networks: overview and challenges. *Communications Surveys Tutorials, IEEE*, 8(1):24 –37, quarter 2006.
3. Antony I. T. Rowstron, Anne-Marie Kermarrec, Miguel Castro, and Peter Druschel. Scribe: The design of a large-scale event notification infrastructure. In *Proceedings of the Third International COST264 Workshop on Networked Group Communication*, NGC '01, pages 30–43, London, UK, UK, 2001. Springer-Verlag.
4. P.R. Pietzuch and J.M. Bacon. Hermes: a distributed event-based middleware architecture. In *Distributed Computing Systems Workshops, 2002. Proceedings. 22nd International Conference on*, pages 611 – 618, 2002.
5. Umar Farooq, Eric W. Parsons, and Shikharesh Majumdar. Performance of publish/subscribe middleware in mobile wireless networks. *SIGSOFT Softw. Eng. Notes*, 29:278–289, January 2004.
6. Y. Toor, P. Muhlethaler, and A. Laouiti. Vehicle ad hoc networks: applications and related technical issues. *Communications Surveys Tutorials, IEEE*, 10(3):74 –88, quarter 2008.
7. Frédéric Besse, Fabien Garcia, Alain Pirovano, and José Radzic. Wireless ad hoc networks access for aeronautical communications. In *AIAA 28th International Communications Satellite Systems Conference*, 2010.
8. T.L. Willke, P. Tientrakool, and N.F. Maxemchuk. A survey of inter-vehicle communication protocols and their applications. *Communications Surveys Tutorials, IEEE*, 11(2):3 –20, quarter 2009.
9. F. Besse, A. Pirovano, F. Garcia, and J. Radzik. Interference estimation in an aeronautical ad hoc network. In *Digital Avionics Systems Conference (DASC), 2011 IEEE/AIAA 30th*, pages 4C6–1 –4C6–11, oct. 2011.
10. J. Blum, A. Eskandarian, and L.J. Hoffman. Performance characteristics of inter-vehicle ad hoc networks. In *Intelligent Transportation Systems, 2003. Proceedings. 2003 IEEE*, volume 1, pages 114 – 119 vol.1, oct. 2003.
11. Sun Xi and Xia-Miao Li. Study of the feasibility of vanet and its routing protocols. In *Wireless Communications, Networking and Mobile Computing, 2008. WiCOM '08. 4th International Conference on*, pages 1 –4, oct. 2008.
12. Fan Li and Yu Wang. Routing in vehicular ad hoc networks: A survey. *Vehicular Technology Magazine, IEEE*, 2(2):12 –22, june 2007.
13. J. Harri, F. Filali, and C. Bonnet. Mobility models for vehicular ad hoc networks: a survey and taxonomy. *Communications Surveys Tutorials, IEEE*, 11(4):19 –41, quarter 2009.
14. H. Hartenstein and K.P. Laberteaux. A tutorial survey on vehicular ad hoc networks. *Communications Magazine, IEEE*, 46(6):164 –171, june 2008.
15. S. Gallagher, D. Blythe, and S. Decker. Communication system architecture for air traffic management and weather information dissemination. In *Aerospace Conference, 2001, IEEE Proceedings.*, volume 3, pages 3/1327 –3/1337 vol.3, 2001.
16. J. Kitaori. A performance comparison between vdl mode 2 and vhf acars by protocol simulator. In *Digital Avionics Systems Conference, 2009. DASC '09. IEEE/AIAA 28th*, pages 4.B.3–1 –4.B.3–8, oct. 2009.
17. Patrick Eugster, Benoît Garbinato, and Adrian Holzer. Pervaho: A specialized middleware for mobile context-aware applications. *Electronic Commerce Research*, 9(4):245–268.

18. R. Meier and V. Cahill. Steam: event-based middleware for wireless ad hoc networks. In *Distributed Computing Systems Workshops, 2002. Proceedings. 22nd International Conference on*, pages 639 – 644, 2002.
19. A. Holzer, P. Eugster, and B. Garbinato. Alps - adaptive location-based publish/subscribe. *Comput. Netw.*, 56(12):2949–2962, august 2012.
20. Davide Frey and Gruia-Catalin Roman. Context-aware publish subscribe in mobile ad hoc networks. In *Proceedings of the 9th international conference on Coordination models and languages*, COORDINATION'07, pages 37–55, Berlin, Heidelberg, 2007. Springer-Verlag.
21. Patrick Th. Eugster, Pascal A. Felber, Rachid Guerraoui, and Anne-Marie Kermarrec. The many faces of publish/subscribe. *ACM Comput. Surv.*, 35:114–131, June 2003.
22. I. Leontiadis, P. Costa, and C. Mascolo. Persistent content-based information dissemination in hybrid vehicular networks. In *Pervasive Computing and Communications, 2009. PerCom 2009. IEEE International Conference on*, pages 1 –10, march 2009.
23. P. Eugster, B. Garbinato, and A. Holzer. Design and implementation of the pervaho middleware for mobile context-aware applications. In *e-Technologies, 2008 International MCETECH Conference on*, pages 125 –135, jan. 2008.
24. Gianpaolo Cugola and Gian Pietro Picco. Reds: a reconfigurable dispatching system. In *Proceedings of the 6th international workshop on Software engineering and middleware*, SEM '06, pages 9–16, New York, NY, USA, 2006. ACM.
25. L. Mottola, G. Cugola, and G.P. Picco. A self-repairing tree topology enabling content-based routing in mobile ad hoc networks. *Mobile Computing, IEEE Transactions on*, 7(8):946 –960, aug. 2008.
26. G. Cugola, A. Margara, and M. Migliavacca. Context-aware publish-subscribe: Model, implementation, and evaluation. In *Computers and Communications, 2009. ISCC 2009. IEEE Symposium on*, pages 875 –881, july 2009.
27. Helge Parzyjegla, Daniel Graff, Arnd Schröter, Jan Richling, and Gero Mühl. Design and implementation of the rebeca publish/subscribe middleware. In Kai Sachs, Ilia Petrov, and Pablo Guerrero, editors, *From Active Data Management to Event-Based Systems and More*, volume 6462 of *Lecture Notes in Computer Science*, pages 124–140. Springer Berlin / Heidelberg, 2010. 10.1007/978-3-642-17226-7.
28. Ludger Fiege, Felix Gartner, Oliver Kasten, and Andreas Zeidler. Supporting mobility in content-based publish/subscribe middleware. In Markus Endler and Douglas Schmidt, editors, *Middleware 2003*, volume 2672 of *Lecture Notes in Computer Science*, pages 998–998. Springer Berlin / Heidelberg, 2003. 10.1007/3-540-44892-6.
29. J.L. Martins and S. Duarte. Routing algorithms for content-based publish/subscribe systems. *Communications Surveys Tutorials, IEEE*, 12(1):39 –58, quarter 2010.