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Type-2 fuzzy decision support system to optimise MANET integration into infrastructure-based wireless systems

A.J. Yuste [a], A. Triviño [b,*], E. Casilari [c]

[a] Dpto. Ingeniería de Telecomunicación, Universidad de Jaén, Spain
[b] Dpto. Ingeniería Eléctrica, Universidad de Málaga, Spain
[c] Dpto. Tecnología Electrónica, Universidad de Málaga, Spain

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ABSTRACT

Mobile ad hoc networks are able to extend the coverage area of Internet access points by establishing multihop communication paths. Due to diverse factors such as the mobility of the nodes, the propagation conditions or the traffic status, the communication paths present a lifetime. In fact, the quality of the Internet connection mainly depends on the durability of the employed communication routes. In order to improve the network performance, the nodes should select the best route in terms of its remaining lifetime. Since the factors impacting the route lifetime are unpredictable, the route remaining lifetime cannot be analytically derived. Under these circumstances, a fuzzy-logic system outstands as a potential solution to estimate the stability of the routes. This paper analyses the potentiality of this kind of solution. In particular, the paper presents a fuzzy logic system which should be installed in the mobile nodes to distributedly identify the stable routes. In particular, the system is supported by an interval-based type-2 fuzzy logic. Being a type-2 fuzzy logic system, it is able to cope with inexact estimations. This ability is necessary to avoid the use of additional messages which will occupy the scarce wireless medium. On the other hand, an interval-based fuzzy system provides the simplicity demanded by the energy-constrained mobile devices. As a novelty, the two outputs of the interval-based fuzzy system are employed. The use of each output depends on the traffic state of the mobile node. By means of extensive simulations, we demonstrate the goodness of the proposed system.

1. Introduction

Wireless telecommunication networks have considerably evolved since their early stages mainly due to the inclusion in the mobile devices of some Internet-based services such as social networks or information retrieval applications. Nowadays the development of wireless networks focuses on satisfying the user requirements of being connected anywhere and anytime. To enable this 4G (Four Generation) context (Natkaniec et al., 2011), some techniques are still needed so that the global access is guaranteed.

Among the networks that are currently under development, we can mentione wireless personal, vehicular or sensor networks. These networks are globally known as Mobile Ad hoc NETworks (MANETs). Despite the ongoing and numerous techniques associated to MANET technology, they are all based on the multihop routing paradigm. By following this routing strategy, wireless nodes communicate even when they are not directly connected. To achieve this goal, distant nodes rely on other network devices that collaboratively retransmit the data from the origin to the final destination. In particular, ad hoc routing protocols are in charge of discovering the sequence of network nodes through which the data are forwarded, that is, to say the communication route. They also have to operate when the mobility of the nodes provokes changes in the routes. It is in these protocols where the above mentioned enhancement can be introduced to facilitate the Internet connection. Under these circumstances, one element in the MANET (known as the Internet Gateway) provides the access to the Internet. To inform the rest of the MANET members about this functionality, the Gateway emits specific messages generically known as MRAs (Modified Router Advertisements) (Singh, Kim, Choi, Kang, & Roh, 2004). In turn, the nodes receiving the messages retransmit them to the rest of the components of the network in order to propagate the data information that the messages contain. It is worth noting that the Internet connection for a node that has not received the message is not possible since the MRA messages inform about the configuration parameters required for the connection. Furthermore, the reception of the message enables the creation and/or optimization of the routes to the Internet from the mobile nodes. When this routing information is not available or valid, the node is forced to emit a MRS (Modified Router

* Corresponding author. Tel.: +34 951 95 23 57.
E-mail address: atc@uma.es (A. Triviño).

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Solicitation) message which is propagated in the network until it reaches the Gateway. This element replies with an unicast MRA, so it is only transported through the route established between the Gateway and the node. Taking into account the use that the mobile nodes make of the MRA messages and the consequences of not receiving them, it is understandable that the way how these messages are propagated (process known as the Gateway discovery) will dramatically impact on the network performance. In this sense, the Gateway can emit the messages on demand, periodically or following a combination of these approaches (Wakikawa, Tuimonen, & Clausen, 2005). The suitability of each type of emission depends on the network and traffic conditions (Hamidian, 2009).This paper will focus on the optimized retransmissions of MRA messages in a proactive mechanism, i.e., a mechanism where the MRA messages are periodically generated by the Gateway every *T* seconds. Following the conventional proactive approach, every node receiving the MRA will retransmit it to its neighbours. This simple retransmission is not adequate for a resource-constrained network such as a MANET. In addition to the cost of retransmitting the message (in terms of energy consumption and aggregated wireless interference), the MRA message can be of no use if the route about which it is informing is not stable, that is, valid in the very next future.

In order to avoid the inconvenient retransmissions through unstable links, this paper presents an adaptive technique to be implemented in the MANET nodes so that they can decide about the suitability of forwarding the message according to the route stability. Due to the unpredictable nature of ad hoc nodes (because of their movements and the wireless interferences or the radio noise), an artificial intelligence based approach is proposed. In particular, the difficulty of characterizing the stability of a wireless link has prompted the use of a Type-2 Fuzzy control system. Type-2 Fuzzy control systems have demonstrated their ability to cope with the combination of several parameters (which could indicate the link stability in our case), specially when these parameters can include uncertainties in their measurements.

The rest of the paper is structured as follows. Section 2 justifies the use of a type-2 fuzzy system in this application. Section 3 introduces different concepts related to fuzzy logic. Section 4 explains the inputs and the output of the decision employed system to optimise MANET performance. The application to the connection to the Internet is analyzed in Section 5 and the configuration of the system is presented in Section 6. Section 7 compares the performance metrics obtained by different MRA forwarding approaches (including our proposal). Finally, Section 8 contains some concluding remarks.

2. Need for a type-2 fuzzy logic decision system

Different works in the literature have already proposed policies to adapt the retransmission of the MRA messages to the network conditions in a MANET (Javaid, Rasheed, Meddour, & Ahmed, 2008). However these adaptive schemes are not based on a complete mathematical characterization of the network behavior. Moreover, these techniques are merely founded on assumptions and heuristics as far as there is not any analytical model that defines the convenience of retransmitting a MRA message. This lack is motivated by the unpredictable nature of MANET nodes and the wireless medium.

Among other factors responsible for this uncertainity, we can outline the following ones:

- The randomness of the movement of the nodes. This causes the links to be frequently activated and deactivated. As a consequence, the topology of MANETs may change rapidly in very short intervals of time. However, in most applications nodes are unaware of other nodes' movement, so routes are normally created without taking into account the durability of the existing links.
- The heterogeneity of the devices that connect to the ad hoc network. This heterogeneity implies a random behavior in terms of transmission range, reception sensitivity, power levels, energy consumption, etc.
- The external interferences due to other technologies and devices operating in the same ISM frequency band (e.g., Bluetooth or infrastructure Wi-Fi). These interferences and the intrinsically variable nature of the radio channel increase the instability and unpredictability of the links in the MANET.
- The presence of traffic bottlenecks. Depending on the location and the number of gateways, traffic bottlenecks may appear in some parts of the ad hoc network. This will drastically reduce the bandwidth of the links. As the bottleneck is a dynamic concept that varies with time according to traffic patterns and existing paths, this uncertainty is difficult to diagnose and correct.
- The difficulty of taking accurate and detailed metrics describing the network status. The estimators used to calculate the variables that determine the adaptation processes are based on a small set of measurements. The individual MANET nodes compute these measurements from a moderate number of events under a limited and partial vision of the network. For example, in the MSC (*Maximal Source Coverage*) algorithm (Ruiz & Gomez-Skarmeta, 2004) the TTL (*Time to Live*) value, which determines the area in which the MRA is propagated, is estimated only after the last data packet is arrived for each connection. Thus the decision to make is very dependent on a single event. More accurate measurements may be obtained by increasing the number of exchanged messages in the network. However, this additional exchange of information will incur in an unaffordable cost in terms of energy or bandwidth consumption.

The complex interaction of all these factors imposes a strong no-linearity to the resulting system, which cannot be analytically treated without enormous simplifications. Thus, there is not a common and validated mathematical approach to help solve all the problems related to the management of MANET traffic. The high uncertainty and randomness of ad hoc networks lead us to believe that type-2 fuzzy logic is a good choice to dynamically adjust some aspects of the integration of ad hoc networks into the Internet. In particular, this paper suggests that a fuzzy logic policy designed to manage and disseminate the MRA messages can help to improve the MANET performance.

Fuzzy logic has shown its ability to cope with information with a high degree of uncertainty in heterogeneous engineering fields. In fact, its use is widespread in many fields of knowledge, for instance in the research on biodiesel (Yuste & Dorado, 2006), communication networks (Trujillo, Yuste, Casilari, & Diaz-Estrella, 2006), processing of voice and music (Muñoz-Expósito, García-Galán, Ruiz-Reyes, & Vera-Candeas, 2007), sensor networks (Fernández-Prieto, Canada-Bago, Gadeo-Martos, & Velasco, 2010), distributed computing (Prado, Galan, Exposito, & Yuste, 2010; Sanchez-Santiago et al., 2008), wireless mesh networks (Khoukhi, El Masri, Sardouk, Hafid, & Gaiti, 2011), vehicular networks (Abdelkader, Naik, & Nayak, 2011) or voice over the Internet (Dogman, Saatchi, Al-Khayatt, & Nwaizu, 2011). MANETs constitute another interesting ambit for the application of fuzzy logic. In (Nie, Wen, Luo, He, & Zhou, 2006), a fuzzy logic controller is used to adapt the security functions of the MANET to the dynamic conditions of the mobile nodes. Similarly, authors in (Zhang, Cheng, Feng, & Ding, 2004) propose a fuzzy logic based routing algorithm, which selects the best path from the definition of a metric that supports