Future Autonomic Cooperative Networks

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Abstract. Both cooperative transmission and autonomic networking have emerged recently as very promising technologies ready to become the key components of the concept referred to as the Future Internet. Cooperative transmission has been one of the hottest research topics lately capitalizing on the exploitation of relay nodes, while autonomic networking is promoting a very desirable vision that networked systems should be able to act as a living organisms and self-configure without any external intervention. This paper promotes the idea of joint approach to both technologies so the end users are benefited in terms of the quality of services they are provisioned.

Keywords: Cooperative transmission, autonomic networking, service provision, Future Internet.

1 Introduction

Both cooperative transmission [7] and autonomic networking have emerged recently as very promising technologies ready to become the key components of the concept referred to as the Future Internet. On the one hand, there is the cooperative transmission being one of the hottest research topics lately which capitalizes on the exploitation of radio channel diversity provided by additional relay nodes. On the other hand, there exists the paradigm of autonomic networking based on the idea that a given networked system should be able to act as a living organism so that it is able to self-configure without any external intervention. Now, as the topic of Future Internet has become the focal area of interest investigated thoroughly be the research community, both approaches seem to be coming to a common point. In particular it is of prime importance to guarantee seamless service provision so end users can observe actual benefits resulting from the latest advances in modern communications systems. There is then an urgent need to devise networked systems that would be able to self-manage so they offer the best possible service to end users while strictly following the policies imposed by network operators. Consequently, such a system would have to express the ability to analyse the current situation and then make an attempt to benefit from the gains offered by cooperative transmission by means of the concept of autonomic networking in terms of configuring network devices properly so they are able to expose certain cooperative behaviours. The concept presented in this paper is developed as a part of the Generic Autonomic Network Architecture (GANA) [2].

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The paper is organised in the following way. First the concept of virtual antenna array aided space-time block coded cooperative transmission is outlined together with the considerations about its applications and specific topics of research. Then the section about autonomic networking follows, where the paradigm of autonomicity is presented along with a discussion about the facilitation of certain network behaviours such as an ability to instantiate cooperation among nodes. The discussion is carried out in the context of service provision for the Future Internet. Conclusion outlines the main points of the analysis and brings the closing remarks.

2 Cooperative Transmission

The idea of cooperative transmission aims at improving the reliability of wireless mobile communications through the use of diversity that can be provided thanks to additional network nodes assisting in the transmission between the source node and the destination node. This is in fact possible because the rationale behind space-time processing can be easily mapped onto networking as long as tight synchronization is guaranteed. In other words, network nodes can be perceived as the elements of a virtual antenna array [5] and they can act as a distributed space-time encoder [9]. The basic approach is described in Figure 1 and the transmission takes two stages.

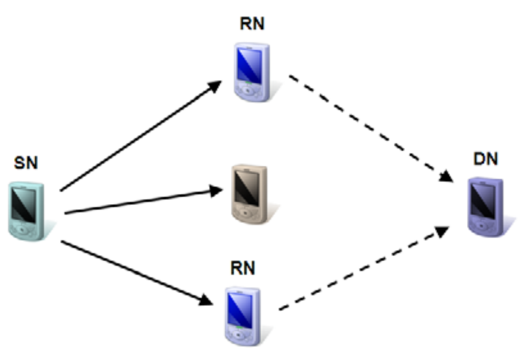

Fig. 1. Generalised virtual antenna array concept

First, the source node (SN) broadcasts the data to be delivered to the destination node (DN) and the relevant information is received by the intermediary node(s). Each of these nodes might become a relay node (RN) and during the second phase only the intermediary nodes selected as relays are entitled to resend the received data towards the destination. This process requires proper synchronisation and application of a spatial-temporal processing technique to orthogonalise the wireless radio channel.

Different spatial-temporal processing techniques can be taken into account and in this paper the emphasis is laid on space-time block coding while the other techniques are generally equally well applicable to the presented concepts. The simplest space-time block code G_2 is defined below (1) to outline the basic operation of space-time processing aiming at wireless channel orthogonalisation, as well as to better illustrate its relation to the concept of virtual antenna arrays.

$$G_2 = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} \quad (1)$$

The operation of a space-time block encoder (or its distributed version in the form of a virtual antenna array) for the presented matrix of the G_2 code can be described as follows: in the first time slot the x_1 and x_2 symbols are sent by the first and second transmit antenna respectively and then, in the second time slot, the $-x_2^*$ and x_1^* symbols are transmitted alike. As it has been already mentioned this operation can be translated to virtual antenna array aided cooperative transmission by simple substitution of antennas with network nodes and by the addition of certain network logic able to provide the notion of cooperative processing.

Cooperative transmission is not only applicable to mobile ad hoc networks, mesh networks or sensor networks but there already exist interesting applications to the next generation cellular systems as well [6] (see also the evaluation results contributed by the author to [8]). Regardless the environment, however, in most of the cases there is a need to answer the question of the selection of relay nodes to be included in a virtual antenna array. The question of transmit antenna selection was similarlyl applicable to plain space-time coding systems where one could have observed benefits from proper antenna selection [12]. For networked systems, however, this issue becomes even more substantial and complex as the network topology may be changing rapidly. One of the proposed approaches assumes the employment of specific existing routing layer mechanisms for the purposes of gaining access to and capitalising on topology information readily available at the network layer. In particular the Optimised Link State Routing protocol (OLSR) [4] is used which belongs to the proactive group of routing protocols tailored to Mobile Ad hoc Networks (MANET). The obvious advantages of the OLSR protocol include its ability of proactive network topology discovery and its inherent optimised broadcasting mechanism in the form of the multipoint relay (MPR) station selection heuristic. As described in [14] and [13] the modification of this mechanism allows for a seamless integration of the concept of virtual antenna aided and space-time block coding based cooperative transmission into the existing protocol. In other words, thanks to careful extensions to the OLSR protocol ensuring its backward compatibility one is able to capitalise on the routing mechanisms and additional information readily available at the network layer for the purposes of optimising the performance of a link layer system employing the aforementioned virtual antenna arrays. The applicability of multi-point relay selection heuristic is outlined in Figure 2.

Analysing Figure 1 and Figure 2 one can see that both the concept of virtual antenna arrays and the multi-point selection heuristic overlap in the sense that multi-point relay stations can cooperatively constitute virtual antenna arrays,

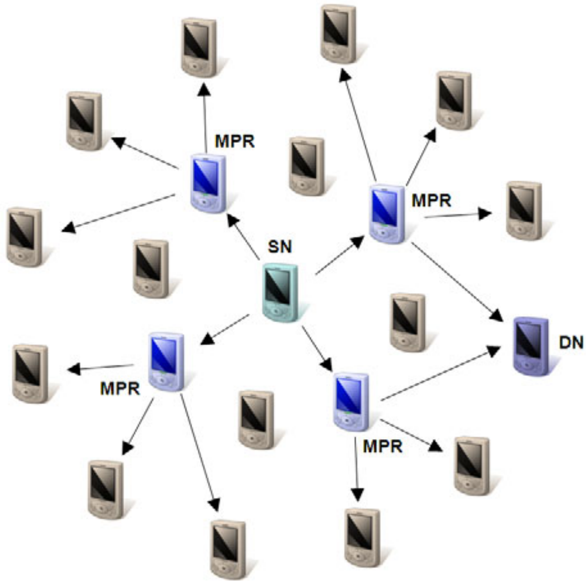

Fig. 2. Multi-Point Relay Stations

i.e. the nodes denoted ad MPRs can take the role of RNs. An important aspect here is that both approaches can be seamlessly integrated into an operating protocol which is continually further developed [3] and will be certainly deployed in the future. The reader is referred to [14] for additional details and analysis of this approach while more information about incorporating this idea as one of the key building blocks of the future autonomic networking will be outlined in the remainder of this paper. Especially on the verge of introducing the Future Internet envisioning wide use of the end user mobile communications devices one can expect the presented issue of cooperative transmission to become one of the key elements of the systems to be devised. The concept of assigning nodes to a virtual antenna arrays is particularly vital when viewed from the network perspective. In that case numerous concurrent cooperative transmissions may occur at the same time and the network itself will have to handle the provision of certain quality of service not only according to user demands but also keeping in mind the policies imposed by a network operator. Autonomic networking seems to be a straightforward approach to addressing this question.

3 Autonomic Cooperative Networking

Autonomic networking has emerged as one of the most promising approaches towards the instantiation of the self-managing Future Internet [2]. Although it attracts a lot of attention, the notion of autonomicity should not be, however, mixed with cognition or the ability of being autonomous. An autonomic system is simply characterised by the ability to self-configure without a need for any external intervention. On the contrary an autonomous network is expected to display certain dose of cognition which is a very interesting add-on to autonomicity and is in the scope of this work. The inherent feature of autonomic networking is a need for continuous monitoring so the network is able to self-configure according to the imposed policies and taking into account additional information about incidents that through proper fault-management can improve the service resilience [1]. The aforementioned factors are particularly important for mobile ad hoc networks which depending on the scenario might be characterized by a very dynamically changing topology affecting the ability of nodes to cooperate efficiently.

In general, such an autonomic network should behave like a living organism which is continually driven by a very large number of processes running on their own but remaining in close correlation without any specific need for intervention form a central entity for most of the time of operation. To map such a concept onto networked systems one needs to apply specific network engineering mechanisms which are currently undergoing pre-standardisation [11]. Particularly, the idea of control loops is applicable to such systems, where a decision element (DE) is controlling a managed entity (ME) based on a closed information flow and with the use of external monitoring and policies related data (Figure 3).

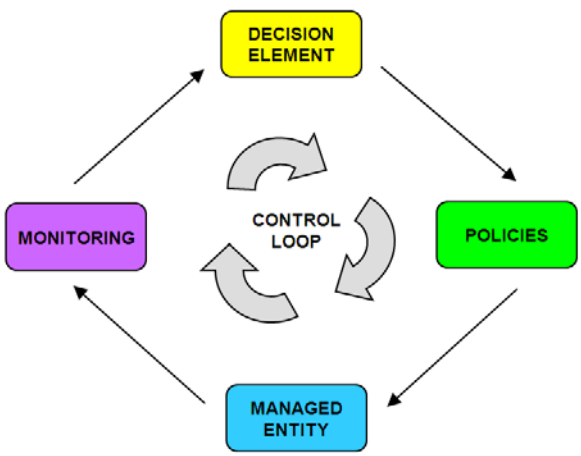

Fig. 3. Generic control loop

It is crucial to note that not only distinct nodes should express autonomic behaviours but the network should be autonomic as a whole. Consequently, it is expected that the network should continuously monitor itself and be able to allign its current operation with the requirements arising from monitoring data or simply imposed by (changing) policies. It means that distinct nodes should express autonomic behaviours but in specific cases decisions might need to be taken at the network level. As a result in certain circumstances the freedom of a decision element to make decisions based just on the available information can be limited by directions given by a higher level decision element. The decisions might need to be taken at the network level in order to make it feasible for the network to perform tasks of a global scope. At the same time different operations, such as cooperation between or among nodes can be carried out without any interruption as long as this does not result in a violation of the rules. Whether to exercise autonomic behaviours at the node and/or at the network level depends on the character of the environment. Full ability to exercise autonomicity at nodes might be of prime importance for mobile ad-hoc networks formed by the end use where it is the user to cover the costs. On the contrary, one would probably emphasise the autonomic network features when network operator devices are concerned. Ideally, the network should be autonomic and at the same time the autonomic behaviours of distinct nodes should not be affected. It means that in case there is a need for a mobile ad-hoc network to request a node to act as a router, the node should be offered some benefits (e.g. free-of-charge access to services, et.) that could compensate, e.g., for quicker battery drainage. One can indeed think about certain mechanisms for motivating the nodes to autonomously trade their level of autonomicity for some benefits in order to make it possible for the whole group to meet predefined goals. An autonomic network formed of autonomic components should be then able to carry out certain internal negotiations in order to reach a common agreement. This is done through the interactions among decision elements and as a result service is more likely to be guaranteed in situations where typically it would be very difficult or even impossible to be handled.

The question of service provision in future autonomic cooperative networks has many very interesting aspects and the cooperation between/among nodes is one of them [10]. Similarly to the aforementioned situation, where specific users might not be willing to agree to become routers, also nodes that could guarantee the required level of service through mutual cooperation at the link layer might not want to do so. There are many degrees of freedom and mechanisms for sorting similar problems out need to be devised. Again the notion of autonomicity can be instantiated here through the interaction between the decision element and its managed entity, which might be e.g. a routing protocol such as OLSR. For the OLSR protocol it is possible to define willingness of a node to carry and forward traffic. This is one of the links to introducing autonomicity. Another aspect is the multi-point relay station selection heuristic which uses this parameter and can be aligned with the concept of virtual antenna array aided cooperation through distributed space-time block coding. The issue of willingness has an implication on the type of cooperation. Actually, cooperative transmission might not always be possible and there might be an urgent need to schedule different cooperative (Figure 4a and Figure 4b) or even non-cooperative transmissions (Figure 4c) at the same time.

The presentes approach to autonomic cooperative networking in the context of service provision brings up some open questions. First of all, assuming node cooperation to be one of the components thanks to which system performance and coverage can be improved in mobile ad-hoc networks, one ends up with a question regarding the feasibility of encouraging end users carrying their battery

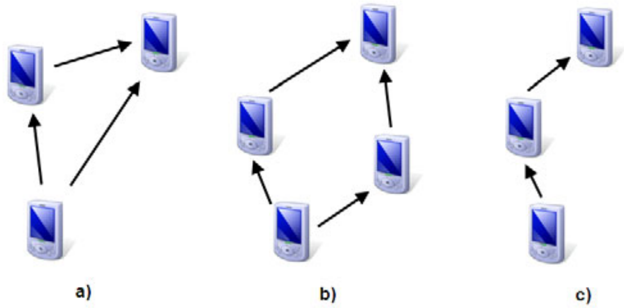

Fig. 4. Potential transmission modes

power limited devices to enter into cooperation. Secondly, assuming this can be done through incentives an optimisation problem arises on how to schedule multiple concurrent cooperative and non-cooperative transmissions, especially when different types of cooperation and relaying are allowed. Finally, making an attempt to capitalise on the paradigms of autonomic networking one comes across the issue of stability and scalability of such an overlay system composed of numerous interacting control loops.

4 Conclusion

Both the idea of cooperative transmission and autonomic networking seem to be the crucial building blocks for the Future Internet. It is envisaged that depending on the situation and policies a network of the future should be able to self-organize in an autonomic way so the expected service provision criteria are met. These criteria may be imposed e.g. by routing, i.e. the network is expected to be able to self-organize so the quality of service requirements for different flows are fulfilled. To this end, the network is expected to schedule autonomically an optimum combination of the aforementioned concurrent cooperative and non-cooperative transmissions and make any necessary updates on the fly. This is crucial for networks composed of battery constrained user devices such as laptops which might not necessarily be willing to offer their resources to be shared through cooperation because of the risk of draining the battery power more quickly. This might have a negative influence on the services offered and special arrangements are necessary so users are encouraged to participate by being granted special incentives. It is then also expected that a network will be able to observe the behaviors of different nodes and learn from this knowledge through cognition.

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