Autonomic Cooperation in Ad-hoc Environments

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***Abstract*—The concept of integrating cooperative transmission with the paradigm of autonomic networking is becoming hotter and hotter these days. Cooperative transmission has proved to bring substantial improvement in terms of increased system robustness, however, especially in dense ad-hoc environments, there appears an urgent need for the incorporation of autonomic routines. In fact, the ability of an ad-hoc network to expose autonomic behaviors would enable the very desirable feature of self-management so that numerous concurrent cooperative and non-cooperative transmissions could be scheduled without any human intervention. Is is especially interesting because, given the fact that proper selection of cooperating nodes can offer local gains, as in the case of the proposed adaptation strategy, the global self-optimization of the system performance becomes realistically attainable.**

I. Introduction

Relay assisted transmission [1], and especially cooperative relaying [2], has attracted a lot of interest recently [3]. This topic becomes extremely interesting in mobile ad-hoc networks where one can employ mobile relays and exploit network layer information for the purposes of optimizing the system performance, observed at the link layer [4], [5]. However, as the current networks are becoming more and more complex, additionally the notion of autonomicity needs to be incorporated. This way the network could self-manage so that cooperation would be arranged in such a way that additional nodes would join as long as service continuity was not affected. In this paper a relevant adaptation strategy, based on [4], [6], and enhanced with the concept of autonomic networking [7], is outlined which offers a tangible gain over a non-autonomic system.

In general, there are different approaches to cooperative relaying known in literature [1] and the one of a special interest for the analyzed concept is based on Virtual Antenna Arrays (VAAs) [8]. Virtual Antenna Arrays can be usually constituted in an ad-hoc manner by the neighbors of the transmitting node, in fact acting together as a distributed space-time block encoder [9]. As a result, the receiving node can exploit additional diversity gain and decode the transmitted signals in a more reliable manner. However, a question arises how to select the nodes taking part in space-time coded cooperative relaying so the transmission parameters are optimized while the overall system performance is not degraded.

Usually, the decision whether a relay node should participate in cooperative transmission or not, is taken depending on its ability to properly receive the signal transmitted by the source node [10], [11]. Unfortunately, in the case of the link layer, the knowledge about the network topology and the parameters of the links, is limited to the closest, one-hop neighborhood only. Therefore, trying to find a reasonable answer to the aforementioned question, one may come to a conclusion that it would be advantageous to further improve the organization of cooperative transmission with the aid of a more detailed information readily available at the network layer. However, plain information seems not sufficient, and what is additionally necessary is the flavor of autonomicity so that cooperative transmission can be actually translated into cooperative behavior(s), being a part of a bigger picture of a network resembling a living organism [12].

The considerations outlined in this paper were performed under an assumption that an accordingly modified version of the Optimized Link State Routing (OLSR) protocol [4], [7] is exploited to provide the managing entities with relevant data necessary for the instantiation of autonomic cooperative networking. In particular, first, the relevant aspects of cooperative transmission are explained in Section II together with some considerations about the network layer protocol. Next, the idea of autonomic networking is presented in context of cooperative transmission in Section III. Finally, the adaptation strategy is detailed and supported with simulation results in Section IV.

II. Cooperative Transmission

The aforementioned concept of virtual antenna arrays may be perceived as the most generalized attempt to make use of the advantages of space-time processing techniques for the needs of cooperative relaying. One of the possibilities is to apply distributed space-time block coding as initially introduced in [9]. Specifically, the relevant system model is depicted in Figure 1, where the process of transmission between the source and destination nodes comprises two phases. During the first phase the source node (SN) broadcasts its signal and so it is received by the destination node (DN), as well as by the potential relay nodes (RNs). Immediately afterwards, this signal is processed by the intermediary relays and eventually it is resent towards the DN during the second phase.

Among different routing protocols there is the OLSR protocol [13], [14] which was primarily devised for Mobile Ad-hoc Networks (MANETs). One of its main advantages is the ability to use the selected nodes only for the purposes disseminating control data. These nodes are called Multi-Point

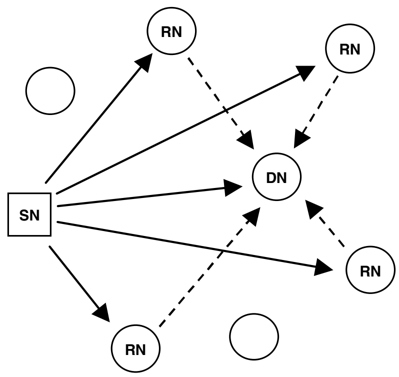

Fig. 1. Virtual antenna array

Relays (MPRs) and are chosen by a given node x out of its entire symmetric one-hop neighborhood. In consequence, all other neighbors reachable by this node, but not belonging to its MPR Set, also receive and process the control messages it broadcasts, however, do not retransmit them any farther (Figure 2). Such an approach is aimed at minimizing the number of redundant retransmissions and therefore optimizing the level of the global control traffic.

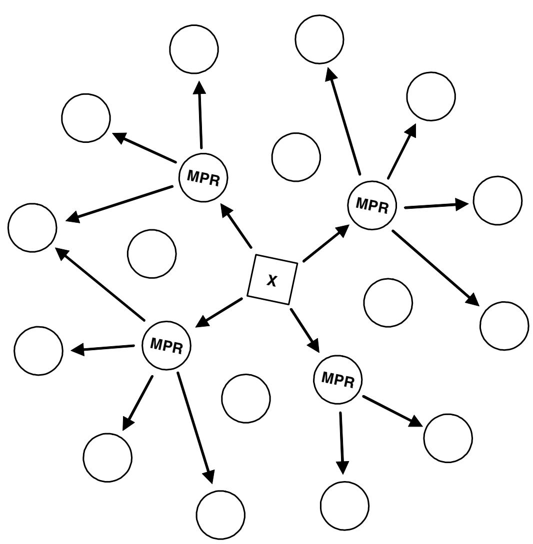

Fig. 2. Multipoint relaying

In order to perform the MPR selection heuristic, the node x must first collect all the necessary information regarding its one-hop and two-hop neighborhoods. To this end, it exploits the data acquired through the reception of Hello messages, periodically transmitted by its one-hop neighbors. More specifically, each one-hop neighbor n of this node advertises its one-hop neighborhood, as well as the status of the corresponding links. Consequently, the node x can identify all its symmetric one-hop and two-hop neighborhoods and on the basis of this information perform the MPR selection heuristic.

It is crucial to note, however, that in general there is no direct correspondence between the concept of multipoint relaying and virtual antenna array aided space-time block coded cooperative relaying. Actually, the original OLSR protocol did not support cooperative relaying at all and so the Routing information Enhanced Algorithm for Cooperative Transmission (REACT) was proposed in [4], [5]. REACT allows to exploit additional routing information for the purposes of enabling and optimizing VAA-based, space-time block encoded cooperative transmission with the use of mobile relays. This is achieved with the aid of an extended version of the Multipoint Relay (MPR) selection heuristic of OLSR. Following, REACT was further enhanced with the notion of autonomicity in [12] and this work is further advanced in this paper.

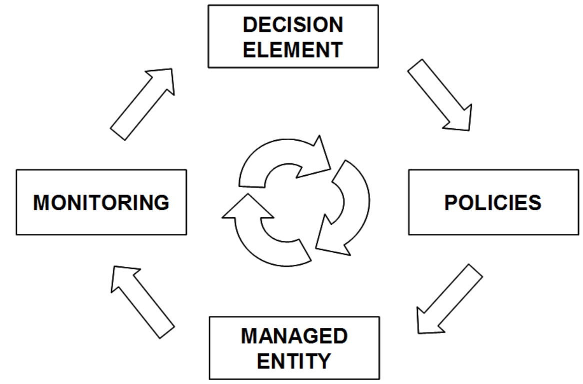

Fig. 3. Generic control loop

III. Autonomic Networking

Autonomicity has emerged as the basis for the instantiation of the network of the future [15]. The key feature of an autonomic system is the ability to self-manage without need for any external intervention. Such systems require continuous monitoring so self-configuration was possible according to the imposed policies and taking into account additional information, e.g. about incidents [16]. The aforementioned factors are particularly important for mobile ad-hoc networks which might be characterized by a very dynamically changing topology.

As mentioned in Section II, such a system is expected to follow the behavior of a living organism. It means it should be continually driven by a very large number of processes running on their own and at the same time interacting among themselves. This way the network should be able to sustain itself and no necessity for external intervention should be assumed. The process of mapping such a concept onto networked systems demands the application of specific engineering mechanisms and this is now undergoing pre-standardisation [17]. The key idea here is the concept of control loops where a decision element (DE) is supervising a managed entity (ME) on the basis of a closed information flow and with the use of external monitoring and policies related data as depicted in (Figure 3).

The question of service continuity in future networks has many very interesting aspects and cooperation among nodes is one of them [18]. In particular, network nodes can autonomically organize into groups in order to sustain service quality through mutual cooperation at the link layer. The notion of autonomicity can be instantiated here through the interaction between the decision element and the routing protocol such as OLSR. Especially, for the OLSR protocol it is possible to define willingness of a node to carry and forward traffic. Another aspect is the MPR selection heuristic, already mentioned in Section II, which uses this parameter and can be aligned with the concept of virtual antenna array aided cooperative transmission. The issue of willingness seems then correlated with the type of cooperation and in this paper an adaptation strategy based on G3 (1) and G4 (2) space-time block codes is investigated.

$$G_3 = \begin{bmatrix} x_1 & x_2 & x_3 \\ -x_2 & x_1 & -x_4 \\ -x_3 & x_4 & x_1 \\ -x_4 & -x_3 & x_2 \\ x_1^* & x_2^* & x_3^* \\ -x_2^* & x_1^* & -x_4^* \\ -x_3^* & x_4^* & x_1^* \\ -x_4^* & -x_3^* & x_2^* \end{bmatrix} \tag{1}$$

$$G_4 = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2 & x_1 & -x_4 & x_3 \\ -x_3 & x_4 & x_1 & -x_2 \\ -x_4 & -x_3 & x_2 & x_1 \\ x_1^* & x_2^* & x_3^* & x_4^* \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ -x_3^* & x_4^* & x_1^* & -x_2^* \\ -x_4^* & -x_3^* & x_2^* & x_1^* \end{bmatrix} \tag{2}$$

Both codes are utilizing the same number of time slots meaning that it is possible to switch between them without any specific penalty in terms of increased system complexity. This actually makes them perfect candidates for the evaluation of the concept of autonomic cooperative networking where an additional node can join a given virtual antenna array to improve transmission robustness, whenever necessary.

IV. Adaptation Strategy

Following the background given in the previous sections and before the adaptation strategy has been outlined, let us define an equivalent distributed autonomic space-time block encoder.

Definition: *A set of perfectly synchronized distributed relay nodes connected to the source node via error-free links and able to cooperatively encode the received signals according to a given space-time block code matrix X_Y, conceptually forms and is defined as an equivalent distributed autonomic space-time block encoder, denoted as E_Y^X.*

Based on this definition an adaptation strategy is proposed which is outlined as Algorithm 1. It is assumed that the two-hop cooperative transmission takes place between the source node x and the destination node $n^{(2)}$. Here the $C(n^{(2)})$ is defined as a set of channel coefficients for the radio channels between all n relays, conceptually belonging to the one-hop neighborhood $N(x)$ of the source node x, and the receiver $n^{(2)}$ in its two-hop neighborhood, $N^{(2)}(x)$. Depending on the threshold value β, this transmission is assisted by at least three out of four intermediary relays. These relay nodes form a virtual antenna array $VAA(x, n^{(2)})$, which is able to encode the received signal in a distributed manner, with the use of either of the space-time block codes outlined in Section III. Consequently, $VAA(x, n^{(2)})$ may be perceived as an autonomic distributed space-time block encoder which is able to operate in both E_3^G and E_4^G mode. On should note that other codes are also applicable and the two were chosen because they are characterized by the same code rate equal to $\frac{1}{2}$ which makes the results directly comparable.

Algorithm 1 Autonomic Cooperation

1: $n = min(C(n^{(2)}))$
2: **if** $C(n^{(2)})[n] < \beta$ **then**
3: $\quad VAA(x, n^{(2)}) \leftarrow VAA(x, n^{(2)}) \backslash \{n\}$
4: $\quad mode \leftarrow E_3^G$
5: **else**
6: $\quad mode \leftarrow E_4^G$
7: **end if**

The E_3^G mode is selected if the minimum value out of the moduli of the channel coefficients is lower than the given threshold β. As a result, one relay node is excluded from $VAA(x, n^{(2)})$ and three others transmit signals in accordance with the E_3^G code matrix. Otherwise four relays are used and the equivalent distributed space-time block encoder operates in the E_4^G mode. This way the worst radio link is autonomically discarded until its parameters meet the criterion of the selection algorithm again.

The results were obtained with the use of the MISO flat fading Rayleigh channel, where the fading coefficients for each wireless link between the relay and destination node were calculated according to the modified and optimized formulas given in [19]. The power transmitted by each of the not excluded relay nodes was normalized so that the overall power, transmitted by all of them, was always equal to unity. The received signal was perturbed by additive white Gaussian noise, characterized by zero mean and $N_0/2$ variance per dimension. Always 40 million bits were transmitted and the QPSK modulation scheme was used. The example results for $\beta = 0.8$ in comparison with the reference curve for the E_4^G encoder are presented in Figure 4 where the achieved gain is about 1 dB.

Following, the detailed results pertaining to the bit error rate improvement at a specific E_b/N_0 for a given threshold β are presented in Figure 5. The achieved improvement may be observed regardless the E_b/N_0 value and the optimum results are located more or less between $\beta = 0.5$ and $\beta = 0.8$. For higher β values there is only a minor improvement. The further ongoing research includes the evaluation of the performance of an adaptive system, additionally employing codes of the rate of 1 and $\frac{3}{4}$, along with different modulation schemes and

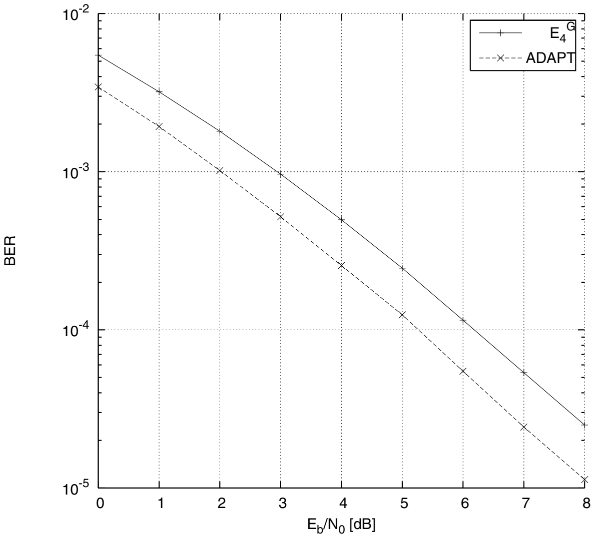

Fig. 4. BER comparison between the E_4^G encoder and the adaptive autonomic system for $\beta = 0.8$

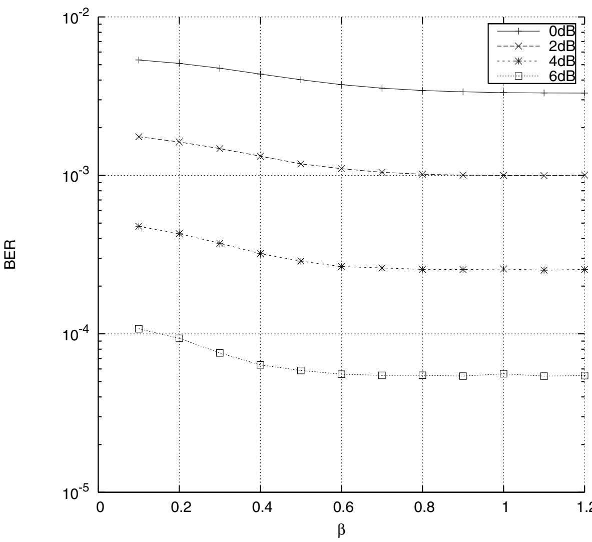

Fig. 5. Performance of the adaptive autonomic system in the function of β for the specific values of E_b/N_0 equal to 0, 2, 4 and 6 dB, respectively

outer coding. It would be then possible to find the optimum β value so the autonomic cooperative system is characterized not only by the lowest bit error rate, but also the most relevant rate code can be used and the optimum system throughput offered.

V. Conclusion

In this paper the topic of autonomic cooperative networking was investigated. In particular the definition of an equivalent distributed autonomic space-time block encoder was introduced and a relevant adaptation strategy was evaluated. It was shown that a networked system can benefit when nodes are allowed to expose autonomic behaviors through cooperative transmission with the aid of network layer routines. The outcome is especially important under the assumption that the autonomic network entities enhance local communication through cooperation only when the overall service continuity is not affected.

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