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COGNITIVE RESOURCE MANAGEMENT OF THE FUTURE UNIFIED NETWORK ARCHITECTURE

BY

EMANUEL PUŞCHIŢĂ[*], REBECA COLDA, ANCUŢA MOLDOVAN, TUDOR PALADE and MARINA ŢOPA

Technical University of Cluj-Napoca

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Abstract. While the necessity of an architectural integration is widely acknowledged, there are numerous controversies regarding the way in which the resource management techniques have to be implemented. In this context, the paper identifies and explores the adaptive potential of resource management techniques to enhance the transmission quality on future unified architectures, both from an evolutionary perspective, through a feedback channel or based on cross-layer interaction, and from a clean slate approach, by making use of the network virtualization concept.

Key words: resource management; feedback; cross-layer; network virtualization.

1. Introduction

Technological convergence towards a unified network architecture is a powerful infrastructure for integrating the next generation of services delivered to the user. By increasing the interest on unifying the network architectures, the concern in the inability of current resource management techniques to respond properly to differentiated requirements of applications is also increasing. Since the resources are limited and the demand for more and more complex services is increasing, only cognitive management techniques are considered as powerful

[*]Corresponding author: *e-mail*: Emanuel.Puschita@com.utcluj.ro

means for improving the network performances (Iera & Molinaro, 2005; Xiuhua *et al*., 2006). While the necessity of an architectural unification is widely acknowledged, there are numerous controversies regarding the way this integration is produced. Hence, a growing number of research initiatives are dealing with questions on how network management is to be accomplished (Ng & Yan, 2006; Jennings *et al*., 2007). This is why the task of providing resource management over unified network infrastructure is proving to be an important challenge in the area.

Conceptual reshaping of the future unified network is proving to be rich in variety, its growing interest being catalyzed by finance opportunities from the EC (European Comission) in Europe and NSF (National Science Foundation) in the USA. Although conceptually different, there are two dominant design solutions for the future network: evolutionary, non-disruptive changes over the time (Dovrolis, 2008) *versus* revolutionary, redesign form a clean slate approach (*e.g*. 4WARD (Mingardi *et al*., 2009), AUTOI (Mamatas *et al*., 2010), 4D (Greenberg *et al*., 2005)). One fundamental attribute of the resource management techniques is the capacity to automatically adapt to the variable network's conditions. This characteristic reflects their cognitive capacity. Therefore, the adaptive potential of resource management techniques will be an inseparable part in the performance evaluation process.

In Section **1**, the paper identifies and explores the adaptive potential of resource management techniques so as to enhance the transmission quality on unified architectures, both from an evolutionary perspective, through a feedback channel or based on cross-layer interaction and from a clean slate approach, by making use of the network virtualization concept.

Within this goal, Section **2** aims to evaluate the network's adaptive potential, at the transmitter side, mainly with respect to the available coding techniques and adaptive modulation and coding schemes that can be employed. As demonstrated, all these mechanisms lead to a significant improvement of the system's performance, provided that a real time feedback loop exists.

In Section **3** we evaluated the adaptive potential of spatial transmit processing techniques, pre-coded or based on a cross-layer interaction, considering the imposed application requirements. When due to operational costs or technical constrains the adaptability level with respect to the network configuration parameters is limited, the application's transmission parameters must be adjusted.

Section **4** illustrates the adaptive potential of resource management techniques at the application level, by making use of network virtualization.

Finally, the conclusions are drawn in Chapter **5**.

2. Adaptive Resource Management Techniques Based on a Feedback Loop

Adaptive resource management techniques, that request or include a feedback loop reaction from the physical network level to the data processing or multi-antenna transmission (Tx) / reception (Rx) blocks, are typically deployed and implemented on existing lower layers of the network. Statistical channel knowledge-based could determine Tx/Rx parameters optimization on several blocks: modulation and coding, multi-antennas system, transmission power control or linear precoding. Therefore, the adaptive resource management techniques using a feedback loop are considered evolutionary design support, argue for continuous enhancements on the existing blocks of the network infrastructure. By using different resource management techniques on the Tx/Rx blocks, the available network resources can be efficiently adapted to the imposed source application requested parameters or to the network context.

Several mechanisms can be employed to maximize the throughput in a time varying channel, but all of these involve the presence of feedback between the transmission and the reception. Feedback is critical especially when we refer to link adaptation techniques, such as adaptive modulation and coding (AMC). Link adaptive techniques rely on the dynamic configuration of certain transmission parameters such as the modulation and coding scheme, according to the variable channel conditions. Consequently, for an efficient management of the available resources, the transmitter needs to be able to anticipate the channel's variations and adapt accordingly to it. The benefits that result from applying a link adaptation technique, in this case the AMC, are illustrated in Fig. 1 for a wireless metropolitan area system.

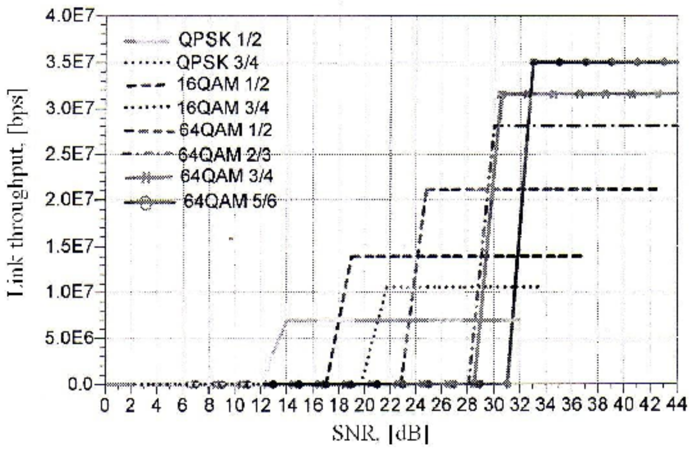

Fig. 1 – Total link throughput for the Ped.*B* channel model using a feedback channel.

The radio channel plays a key role in the link adaptation process, with respect to the evaluation of the transmitter's parameters. One of the most used set of channel models for the simulation of different types of environments affected by frequency-selective fading is the ITU-R set of channel models (WiMAX Forum, 2008), in our case Ped. *B* (Pedestrian *B*) channel model. For most applications a BER (Bit Error Rate) less than 10^{-6} is required. Also, for being able to satisfy even the most bandwidth consuming applications, we impose a minimum of 1 Mbps link throughput even under a worst case scenario. For taking advantage of the random fluctuations of the radio channel and overcoming time-selective fading, an AMC scheme can employed on a per user and per frame basis (Tran *et al*., 2008). In this case, different spectrally efficient modes (where a mode is defined as a combination of modulation and FEC – Forward Error Correction coding rate) can be alternated for increasing the throughput, assuming that the SNR (Signal-to-Noise Ratio) thresholds required for passing from one mode to another are available at the transmitter.

In Fig. 1 the total achievable link throughput for different modes is presented. For high SNR values the highest order throughput scheme will be selected (64QAM 5/6) in order to efficiently use the channel's capacity. During deep fades, when the quality of the radio channel degrades rapidly in time, a lower order throughput scheme will be employed (QPSK 1/2) in order to avoid an excessive number of dropped packets as well as to avoid losing the connection quality and link stability.

Based on the application's constraints and on the fact that each mode needs a certain robustness level in order to be activated (a minimum SNR value), we conclude that each mode is optimal to be used in a different channel quality region. If the channel's variations are sufficiently slow and the channel quality information (received SNR) can be fed back to the transmitter, then by making use of the AMC technique an optimum use of the available radio resources is obtained. In contrast, systems where a link adaptation mechanism is not applied do not allow for an efficient resource management.

3. Adaptive Potential of Spatial Transmitting Processing Techniques Based on Cross-Layer Interaction

Data processing blocks demonstrate a high adaptive potential with respect to the varying radio channel conditions. Still some critical conditions or cost constrains could limit the network's resource optimization level. These situations impose a higher level adaptation process to the available network resources. Cross-layer interaction implies a link between the different network's layers, bottom-up or top-down, by breaking the OSI rules.

The control of the fragment length at the data link layer in conjunction with the spatial transmit processing techniques at the physical layer is a demonstration of the adaptive potential based on the cross-layer interaction. Improving network resource management using cross-layer interaction represents an evolutionary, non-disruptive technique.

Spatial processing techniques have the potential to significantly improve the reliability or the data rate in a rich scattering environment. If the channel condition is made available at the transmitter, it is possible to fully exploit spatial diversity and hence to improve the error performances and the capacity of the system. The amount of channel knowledge at the transmitter influences the adaptive potential of the system. It dictates the design parameters that can be adapted to different channel conditions, according to some application requirements. For this evaluation we consider that the throughput maximization is based on a cross-layer interaction that involves the control of the packet length at the link layer and the use of spatial transmission processing techniques at the physical layer. We assume different configuration on multi-antenna systems, STBC (Space-Time Block Codes) encoded and the same channel model.

For this assessment, only 4PSK modulation is used and the data are not pre-coded before being sent to the transmitting antennas. Moreover, the receiver has perfect channel knowledge and the channel has a relatively small Doppler spread.

The requirement from the application is a minimum throughput value of 1 Mbps, which has to be satisfied even for low values of the SNR, the same as in the previous analysis. The optimum packet length depends on physical layer parameters (Zahidul *et al.*, 2008) such as: input SNR, Doppler rate, constellation size and it involves a tradeoff between the reliability of the transmission, achieved with a short packet length or increased symbol overheads, and the throughput.

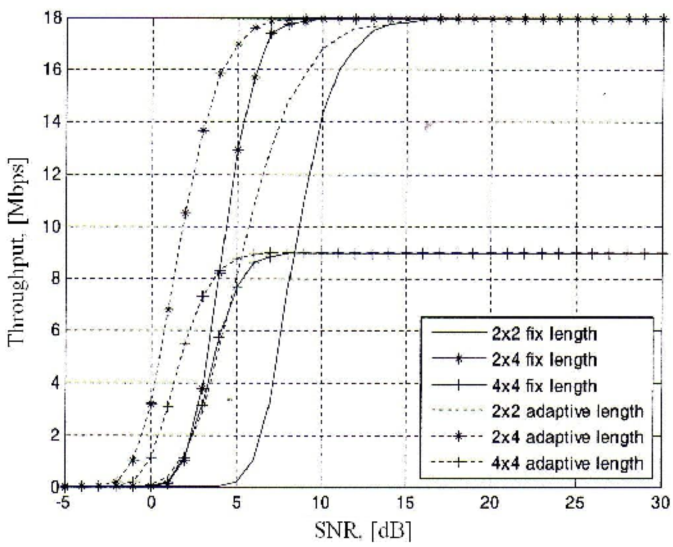

Fig. 2 – The influence of the packet length on link throughput.

From Fig. 2 it can be seen that the transmissions with adaptive packet length outperforms the transmissions with a fixed packet length, for low values of the SNR. A throughput value higher than 1 Mbps can be provided only if the indicator channel is higher than –4 dB, by the 2 × 4 antenna system. For fixed packet length, a value of the SNR higher than 2 dB is needed to ensure a data link throughput of at least 1 Mbps. For lower values of the SNR (SNR < –4 dB), the considered system configurations cannot fulfil the application requirements, as in this case the packet length is the only parameter that is adapted to the channel state. The advantage compared to the previous adaptive method is that the amount of information transmitted on the feedback channel is reduced.

4. Adaptive Resource Management Potential Using Network Virtualization

Despite of the inseparable role that resource management support plays in communication networks, current system specifications are far from totally integrating these functionalities, as the clean slate approach requires. From the previous analysis it is quite obvious that for feedback loop or cross-layer resource management techniques there still is an entity-functionality schism, especially when new support is added to the existing network.

The clean slate approach brought an integrated resource management support having the functions safely lodged in a so-called self-organizing management plan through network virtualization. Network virtualization consists in clustering logical resources into virtual networks and makes each virtual network appear to the user as a dedicated infrastructure, with dedicated resources and services available for application requests (Schonwalder *et al.*, 2009).

The model used to demonstrate the adaptive resource management potential through network virtualization is the I-NAME (In-Network Autonomic Management Environment) model (Puşchiţă *et al.*, 2010). For the I-NAME model, the network virtualization process is assisted by the QoS profiles. Through the QoS profiles, the model defines a set of requested, accepted, negotiated or adapted parameters which are the result of the message exchange in the virtualized network, from the source node (SN) to the destination node (DN). In order to demonstrate I-NAME model's capabilities on guaranteeing self-adaptive resource management, a set of time-critical applications have been transmitted between the SN and the DN under different network conditions: over a BE (Best-Effort) network environment, based on QoS network layer classification (IP Precedence 3 and 6) and with I-NAME support. Using QualNet Developer 4.5 (Scalable Networks…), a unified network scenario which models two radio access segments connected through a core network segment was built. The SN was located in the IEEE 802.11 access network, while the DN was located in the IEEE 802.16 access segment.

Through the QoS profiles the application requests a maximum sensitivity to the transmission delay, the maximum accepted level in the network being 0.01 s. Being a quantitative parametric analysis, the criteria on which the performance evaluation of the I-NAME model was based on, in relation with other support models was the capacity of the source application to gradually adapt to the network context through source coding, while maintaining the requested average end-to-end transmission delay, as shown in Fig. 3.

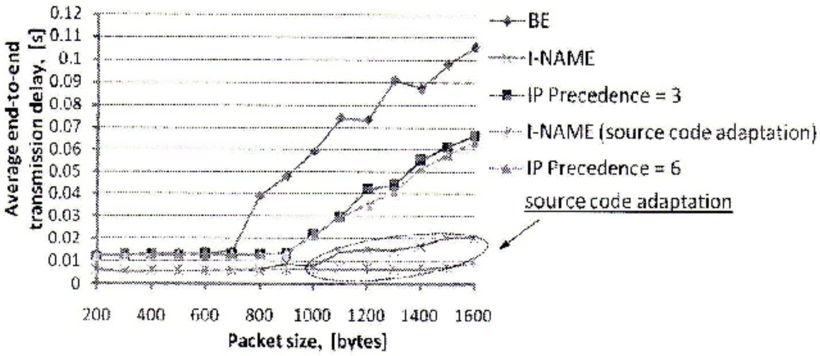

Fig. 3 – The effect of the packet size variation upon the average end-to-end delay.

Even the improvements added by the I-NAME model through network virtualization are significantly better compared to the support offered by the other models, the analysis results indicate the overcome of the minimum imposed delay value of 0.01 s in 40% of cases when the source application packet size varies. When the application requirements exceed the network capacity, the I-NAME model proposes an adaptation of the application parameters, through source code adaptation. The source code adaptation procedure implies gradual adjustment of the inter-packet transmission interval for all the cases in which the surpassing of the maximum accepted average delay value is indicated. After the predictive coding adaptation process, application's average end-to-end transmission delay is kept within the imposed limits. Therefore, the adaptive potential of the application parameters involves network virtualization with respect to the imposed application QoS profile.

5. Conclusions

The goal of this paper was to identify and explore adaptive techniques that can be used for achieving an efficient resource management, in the attempt to enhance the transmission quality of unified network architectures. The presented adaptive solutions have illustrated the capability to efficiently use the available system resources, by applying different techniques based on a feedback loop, on cross-layer interaction or on network virtualization. For systems using a feedback loop, the adaptive potential on resource management was explored through modulation and coding schemes calibration. Cross-layer interaction is based on the control of the packet length, at the data link layer in conjunction with the use of spatial transmission processing techniques, at the physical layer. Through the network virtualization process, the adaptive potential at the application level is emphasized, by applying source coding adaptation. Thus, by realizing adaptation at either the network or application level, these techniques guarantee an efficient resource management.

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GESTIONAREA COGNITIVĂ A RESURSELOR ÎN VIITOAREA ARHITECTURĂ DE REȚEA UNIFICATĂ

(Rezumat)

În vederea îmbunătățirii calității transmisiilor în arhitecturi de rețea unificate se identifică şi evaluează potențialul adaptiv al unor tehnici adaptive de gestionare a resurselor. Din perspectivă evolutivă sunt indicate tehnicile ce utilizează un canal de reacție şi cele bazate pe interacțiunea inter-straturi, perspectiva “clean slate” promovând tehnica de virtualizare a rețelei. Astfel, pentru sistemele cu buclă de reacție, potențialul adaptiv în gestionarea resurselor este explorat prin calibrarea schemelor de modulație şi codare. În cazul interacțiunii inter-straturi, lungimea cadrului este controlată în conjuncție cu tehnicile de procesare spațială de la nivel de strat fizic. În final, tehnica de virtualizare a rețelei evaluează potențialul adaptiv de gestionare a resurselor prin ajustarea treptată a parametrilor aplicației la contextul rețelei.