RESEARCH REPORT

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RATIONALE Project Research Report

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RATIONALE Project Research Report	
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Summary

Cognitive radio systems have recently emerged as potential enablers of more efficient use of various resources in future wireless communication systems. Cognitive radio systems can obtain knowledge of their operational environment and internal state, adapt their operations to optimize performance, and learn from the results. Realization of cognitive radios requires use of adaptive transmission techniques. This research report summarizes VTT's main results from the RATIONALE project in the field of adaptive transmission techniques for wireless networks.

Theoretical studies in RATIONALE have been focused on the analysis and development of adaptive transmission strategies, especially for military use. The work has considered modeling of wireless channels and normalization of them. The selections of correct performance measure are shown to be of critical importance in comparative performance analysis of adaptive transmission systems. We have shown the analogies between decision-theoretic problems and information-theoretic problems in adaptive transmission systems and used this information in designing practical adaptive algorithms. We develop a method for performance evaluation using the rational decision theory and the developed models and use it in power control simulations. Finally, several practical adaptive power control methods are simulated and their performance analyzed. Our proposed filtered-x least mean square (FxLMS) algorithm is shown to be a generalization of practical algorithms.

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Preface

This report covers VTT's main results of the Application of the Theory of Rational Decision-making to Adaptive Transmission (RATIONALE) project carried out 2009–2011. The project was funded mainly by MATINE. VTT's funding covered roughly 15 % of total budget. Research Professor Aarne Mämmelä (VTT) served as scientific leaders of the RATIONALE project.

During the project the discussions with the Lieutenant Colonel (Eng.) Juhani Juntti from the Finnish Defence Forces, has been of great importance and is acknowledged. His feedback and ideas helped to steer the project to right direction.

This research report collects the result from VTT's RATIONALE project team: Marko Höyhtyä, Adrian Kotelba, and Aarne Mämmelä. The contributions of Adrian and Aarne are cordially acknowledged.

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1 Introduction

With the rapid development of mobile Internet services, the forthcoming wireless systems are expected to provide high rate multimedia services. A fundamental problem in designing such a system is how to efficiently allocate the limited resources among the users of the network. New generalized adaptive radios called cognitive radios (CRs) that are using various sensors to estimate the status of the environment and making intelligent decisions based on the obtained information have been proposed to improve the resource use. The aim of CRs is to improve the performance of the network; especially the efficiency of spectrum use has been under study. Realization of cognitive radios requires use of adaptive transmission techniques.

The wireless channel makes the design of wireless communication systems extremely difficult because the channel characteristics change over time in an unpredictable way. Adaptive transmission techniques are currently considered a very promising method to cope with time-varying effects, improve transmission reliability and maximize the use of available resources. The adaptive control rule that governs the selection of transmission parameters with respect to various transmission constraints is usually called an adaptive transmission strategy.

A fundamental problem in the design of adaptive system which operates in a nonergodic channel is the choice of the preferred probability distribution and the corresponding transmission strategy. The determination of the best choice among several alternatives each of which leads to uncertain possibilities is the subject of rational decision-making under uncertainty that is well developed within the framework of financial mathematics.

2 Goal

The RATIONALE project goal was to conduct fundamental research on application of the rational decision theory to adaptive transmission. The aim was to apply the theory in the development of practical adaptive trasnsmission strategy development. In particular, the main goals of the RATIONALE project were to

- Determine efficient practical adaptive transmission strategies achieving almost optimal trade-off between average transmission data rate and the risk associated with that particular data rate for cognitive ad hoc and mesh network scenarios for military communication.
- Determine which are appropriate performance indicators that objectively and meaningfully describe the performance of adaptive systems in those situations?

3 Description

Detailed description of the RATIONALE project activities is presented in [1]. As a summary, the approaches studied by VTT included the following:

- normalization of a multipath fading channel,
- development of channel and diversity models,
- development and analysis of adaptive transmission strategies,
- application of rational decision theory in practical algorithm development including algorithms used in CDMA and LTE systems.

4 Limitations

The research done in the RATIONALE project was long-term fundamental research on general adaptive transmission techniques without focusing on specific wireless telecommunication system standards. The limitation of the work is that the results produced in the project are not directly applicable to a specific system but need further development to match the requirements and capabilities of the actual systems. The applicability of the results to different systems is an important topic for future research.

5 Methods

The main research methods in the project included the following:

- theoretical investigations: theoretical performance evaluation of adaptive power control techniques,
- algorithm design: development and comparison of the algorithms for adaptive power control,
- performance measurement method for practical

6 Results

The RATIONALE project has strengthened VTT's knowledge of adaptive transmission strategies and produced the following results:

- 4 publications
- Presentations at various events
- Final report: Application of the theory of rational decision-making to adaptive transmission (RATIONALE) [1].

More details about the project results are presented in [1]. Scientific research results have been published in various international conferences and journals including 4 publications [2]-[5]. There were 2 meetings where the research results were presented to the customer at VTT's premises. There were active discussions on various adaptive transmission topics with the representative of the MATINE and based on the discussions the focus of the last year of the project was shifted. In addition, in the end of each year, a final presentation of the project was given at the anniversary seminar of MATINE. A new project proposal, JAMCRON, was submitted to MATINE on the topics studied in the RATIONALE project.

7 Validation of results

The performance of the developed algorithms was mainly evaluated with Matlab simulations. Part of the work was analytical where the performance of the algorithms was evaluated analytically. The results were not validated in any specific wireless telecommunication system standard. The applicability of the results in standardized systems is an open issue.

8 Conclusions

The project developed new adaptive transmission techniques and new ways to measure the performance of them. The developed methods were collected into 4 scientific publications. The project reached its targets. Participation in the MATINE seminars has promoted the introduction of adaptive transmission strategies and cognitive radio systems to a large extent. The customer, Finnish Defence Forces, considers the adaptive strategies and cognitive radio systems as important research topics for the future. Especially, the interference and jamming need to be studied in the futures as well as to do more demonstration activities.

9 Summary

Cognitive radio systems have recently emerged as potential enablers of more efficient use of various resources in future wireless communication systems. Cognitive radio systems can obtain knowledge of their operational environment and internal state, adapt their operations to optimize performance, and learn from the results. Realization of cognitive radios requires use of adaptive transmission techniques. This research report has summarized VTT's main results from the RATIONALE project in the field of cognitive and adaptive wireless communication e.g., modelling wireless channels, power control algorithm design, and performance measurement methods for adaptive algorithms. A more thorough summary is presented in [1].

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