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SANTA CLOUDS Project Final Report

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Summary

SANTA CLOUDS project was a joint research project between VTT and University of Oulu, funded by Tekes. This report summarises VTT's research in the project.

SANTA CLOUDS project focused on development of useful techniques and applications exploiting cooperative and cognitive communication principles in a wireless communication system. In most of the practical scenarios there are numerous wireless devices with which a collaborative cluster or cloud can be formed to enable more efficient use of resources such as spectrum and energy. As the nodes of clouds are assumed to be wireless devices, we will refer to this arrangement as a mobile cloud. The nodes of a mobile cloud can exploit their multiple air interfaces, being thus able to connect directly to each other as well as to the base stations. Several techniques suitable for a mobile cloud environment have been developed.

The SANTA CLOUDS project has developed cooperative video streaming methods, focusing on predicting and avoiding video interruptions. Resource management and decision making aspects have been developed from the air interface selection, transmission channel selection, and power control perspectives. The project has analysed the status of the current spectrum occupancy in Industrial, Scientific, and Medical (ISM) band. The project has made experimental studies in sensing management and channel selection using CORAL platform.

International cooperation has been carried out in COST Actions IC0905 TERRA and IC0902 on Cognitive Radio and Networking for Cooperative Coexistence of Heterogeneous Wireless Networks. Results of the work have been reported in international publications, theses, and patent applications. Spectrum measurement and analysis work continues in cooperation with universities from Finland and USA.

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Preface

The Services and applications oriented cooperative and cognitive networking: Mobile Clouds (SANTA CLOUDS) project was conducted at VTT in Oulu, Finland, in 2011–2013. It was a joint research project with Centre for Wireless Communications, University of Oulu. The project was funded by Tekes and the steering board of the project included also Elektrobit, EXFO, Finnish Defence forces, Finnish Communications Regulatory Authority (FICORA), Nokia, Nokia Siemens Networks, Renesas Mobile Europe, and Saagatec.

Marko Höyhtyä acted as a project manager for VTT's part of the SANTA CLOUDS project. The project participants at VTT were Antti Anttonen, Ilkka Harjula, Marko Höyhtyä, Adrian Kotelba, Janne Kusmin, and Aarne Mämmelä, VTT steering group consisted of the following participants: Pertti Järvensivu, and Marko Höyhtyä as secretary. This report summarizes VTT's research in the project.

The contributions from the project participants from all organizations are gratefully acknowledged.

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Contents

1. Introduction

The rapid development of Internet as well as the increasing demands from mobile users create stringent requirements for the forthcoming wireless and mobile communication networks. Heterogeneous multimedia services need to be provided to a multiplicity of users using different terminals. The key challenges include not only enhancing network and link performance (e.g., data throughput, QoS, coverage, network capacity, etc.) but also exploiting radio resources in an efficient manner. Of particular importance are the efficient utilization of spectrum and energy.

A large number of approaches based on cooperative and cognitive principles have received considerable attention lately. Cooperation involves the interaction between two or more entities aiming at obtaining benefits that can be enjoyed by one or more of these entities. In wireless networks, cognition and cooperation are highly complementary techniques and their combined exploitation brings unique advantages.

SANTA CLOUDS was established to exploit these key principles and techniques in a new concept known as mobile cloud. A mobile cloud is a local collaborative arrangement of wireless devices that help each other to improve performance and efficiency in the use of resources of some or all cloud members. Wireless devices cannot only talk to each other but also they can be connected to the overlay cellular network.

2. Goal

Main focus in the project was in developing fundamental enabling techniques for cooperative and cognitive networks keeping all the time possible applications and services in mind. The overall goals of the SANTA CLOUDS project were:

1) Creation of mobile cloud concepts and scenarios. To have good insights on the applications and applicability of mobile clouds as well as on the key enabling technologies.

2) Research and development of cognitive and cooperative methods for selected applications and use cases.

3) Solve issues related to topologies, fundamental algorithms and protocols, and network management aspects.

4) Support contributions for the COST forums and influence on future standards via having an active role in related European projects.

VTT's research work was divided into four work packages (WPs):

WP 0: Project Management

- Management and dissemination of results

WP 1: Use Cases and Applications for Mobile Clouds

- Define concepts, use cases and applications to be studied in later WPs

WP 2: Mobile Clouds: Fundamentals and Applications

- Research and development of cognitive methods applied to certain applications and use cases

- Practical experiments on video transmission and related sensing and channel selections using the CORAL platform
- Measurements of the spectrum occupancy in Industrial, Scientific and Medical (ISM) band.

WP 3: Mobile Clouds Management

- Decision-making in mobile clouds and development of cognitive engine
- Cognitive resource management methods
- Cooperative video streaming methods with prediction and avoidance of interruptions

3. Description

This project has focused on applying cognitive and cooperative techniques to mobile communication systems with the goal to optimize their network resource usage and enable cooperative applications also in the spectrum sharing environment. In particular, this project has been focused on developing new applications and methods for a concept called mobile cloud. The results are discussed in more detail in Chapter 6.

4. Limitations

The SANTA CLOUDS project has focused on fundamental research where results have been mainly theoretical except some experiments on CORAL platform and ISM band measurements. Thus, the proposed methods might need further development and testing in practical environments.

5. Methods

Research methods included simulations and mathematical analysis, development of algorithms for CORAL platform, performance and spectrum measurements, analysis of measurements, literature reviews, and participation in COST actions.

6. Results

The SANTA CLOUDS project has strengthened VTT's knowledge of cognitive and cooperative networks. The achieved results to meet the project's goals are summarized in the following.

6.1 Cooperative video streaming methods

Novel cooperative streaming methods for wireless networks have been developed and analysed. Results on this topic include 1) Simple theory to predict video interruption probability for given video and network delay jitter characteristics. This provides new inference on effect of video length, leading to potential use in online cross-layer decision making for smooth video streaming. Another main result is 2) Analysis of cooperative heterogeneous networks for reducing video interruption probability. This provides new inference on effect of cooperation route starvation. Potential use of this result is in online

decision making for cooperation resource management to solve video interruption user problem. Publications on this topic have been submitted for review.

6.2 Enabling techniques for mobile clouds

Cognitive engine is the management entity of the wireless system that makes the decisions and actions in order to achieve the specified goals. The project has defined guidelines for development of cognitive engine in [1] and studied related resource management problems such as power control for sensing based access in [2] and adaptive power control strategies in [3]. Partly the cognitive engine work was done in parallel with the Tekes funded CORE project where implementation of the cognitive engine was done in the trial environment.

Cognitive spectrum and channel selection methods able to exploit the history data on the use of channels have been developed. The developed methods provide means to reduce collisions between secondary and primary systems, reduce delays in the data transmission, and increase the throughput of the secondary system [4]–[8]. That is enabled by learning and classifying the occupancy patterns of different channels and applying this information to prediction and sensing management purposes.

Energy efficient mmW-detection for short-range links with possible application to small mobile clouds has been developed during the project. The research in this aspect has focused on energy detection of PAM signals [9], [10], [11]. Power consumption of multi-interface mobile cloud has been analysed as well to understand when and how D2D communication should be used instead of pure cellular operation.

6.3 Analysis of ISM band measurements

The project has analysed the results of a measurement campaign conducted in the 2.4 GHz ISM band in Oulu area in several places, including the university and residential area. A specific 24 hour period was selected for analysis. The results were analysed based on different criteria to see how much, if any, space is left for opportunistic operation in this band. The results show that there is always room for opportunistic spectrum use. The analysis showed that one must carefully think what parameters to use in analysis since the resolution of the data affects strongly to the availability results. The results of the analysis were reported in [12].

7. Validation of results

The performance of the proposed methods has been validated mainly by mathematical analysis and simulations. In addition, implementation and experiments have been made with the CORAL platform.

8. Conclusions

The SANTA CLOUDS project has developed concepts and scenarios for mobile clouds. Cooperative and cognitive methods have been developed and investigated. The developed methods form a good basis for future studies and demonstrations on cooperative video streaming, spectrum sharing, and network resource optimisation. Spectrum measurements and developed methods can be used in the real world spectrum sharing experiments.

In the future the developed SANTA CLOUDS concepts and methods will be applied and investigated further in European projects to develop key enabling technologies for the future high-speed broadband and mobile network infrastructures. Spectrum measurement and analysis work continues in cooperation with universities from Finland and USA.

9. Summary

The SANTA CLOUDS project has developed concepts and methods for cooperative wireless networks, specifically for mobile clouds. The project has developed methods to predict and avoid video interruptions in cooperative video streaming. The project has developed cognitive decision making techniques and related enabling techniques for mobile clouds.to optimise the resource use of future networks. The project has analysed the status of the current spectrum occupancy in the ISM band in Oulu area and identified spectrum opportunities. The results have been reported in scientific journals and conferences. Also one patent application was submitted. Project members have contributed in COST Actions IC0905 TERRA and IC0902 on Cognitive Radio and Networking for Cooperative Coexistence of Heterogeneous Wireless Networks.

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