OneFIT
Opportunistic Networks and Cognitive Management Systems for Efficient Application Provision in the Future Internet

Overview and main achievements

ETSI Workshop on Reconfigurable Radio Systems
12 December 2012, Cannes, France
Presentation Overview

- **OneFIT concept**
- **Control Channels for the Cooperation of Cognitive Management Systems (C^4MS)**
  - Example of C^4MS messages
  - C^4MS message types
  - Information exchanged
  - Information detail levels
  - C^4MS data structures
  - Formulas for analytical signaling evaluation
  - Signaling evaluation
- **Algorithmic synergies & integration**
  - Spectrum opportunity identification & selection
  - Selection of nodes and routes
- **Validation activities**
  - Proof-of-Concept Architecture
  - Developed demonstration focus areas
- **Overall benefits and conclusions**
OneFIT concept

- **Main objective:** To design, develop and validate the concept of applying *opportunistic networks* and respective *cognitive management systems* for efficient application/service/content provisioning in the Future Internet.

- **Opportunistic Networks** are operator governed (through resources, policies, and information/knowledge) and can be coordinated extensions of the infrastructure for a particular time interval and in specific place.

- **Challenges:** Suitability determination (candidate node discovery, spectrum opportunity); opportunistic network creation, maintenance and release.

- **Cognitive Management Systems** are exploited for ensuring the fast and reliable establishment of ONs:
  - They can be located in both the network infrastructure and the terminals/devices;
  - Cognitive system for the management of the opportunistic network (CMON);
  - Cognitive management system for coordination with the infrastructure (CSCI).

- **Control Channels for the Cooperation of Cognitive Management Systems (C⁴MS)** are used for the coordination between cognitive systems and the exchange of information and knowledge.
OneFIT high level solution description

- Cognitive management systems
  - Cognitive system for management of opportunistic networks (CMONs)
  - Cognitive system for coordination with infrastructure (CSCIs)

- Control Channels for the Cooperation of Cognitive Management Systems (C^4MS)
  - Coexistence and coordination of different cognitive radio networks and nodes
  - Management of Opportunistic Networks
OneFIT activities

- Business aspects, requirements and technical challenges, evolution of functional and system architecture (WP2)
- Control channels for the cooperation of the cognitive management systems (WP3)
- Algorithms for enabling opportunistic networks (WP4)
- Integration, experiments and validation (WP5)
Evaluation work on $C^4$MS

- Example of $C^4$MS messages
- $C^4$MS message types
- Information exchanged
- Information detail levels
- $C^4$MS data structures
- Formulas for analytical signaling evaluation
- Signaling evaluation
Example of a C⁴MS messages

● Example of C⁴MS message header format

```
0                   1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version| Flags |   Reserved    |           MessageID           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Transaction ID        |    Variable Payload Length    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

● Example of C⁴MS message and C⁴MS MessageID

```
<ONNR> ::= <Header>
            [ Source-C4MS_ID ]
            * [ Destination-
                C4MS_ID ]
            { Negotiation_ID }
            { Reason }
            [ ON-ID ]
            { Context }
            * [ AVP ]
            [ Security_Payload ]

+----------------+----------------+
|                |
|                |
+----------------+----------------+
|                |
|                |
+----------------+----------------+
|                |
|                |
+----------------+----------------+
|                |
|                |
+----------------+----------------+
```

● Message types:
  - Information
  - ON_Suitability
  - ON_Negotiation
  - ON_Creation
  - ON_Modification
  - ON_Release
  - ON_Status

● Opcodes:
  - Request
  - Answer
  - Indication
C⁴MS message types

- **Messages between CSCI-CSCI (CI interface)**
  - Information.Request/Answer, Information.Indication
  - ON_Suitability.Indication
  - ON_Status.Notification

- **Messages between CMON-CMON (OM interface)**
  - Information.Request/Answer, Information.Indication
  - ON_Negotiation.Request/Answer
  - ON_Creation.Request/Answer
  - ON_Modification.Request/Answer
  - ON_Release.Request/Answer
Work will focus on exchanged information related to:
- Profiles
- Context
- Policies
- Decisions
- Knowledge

Specific data structures are defined which will cover the information needs for:
- The coexistence and coordination of different cognitive radio networks and nodes, operating in unlicensed bands like the ISM band or as secondary users in TV White Spaces;
- For the management of operator-governed Opportunistic Networks-ONs (as defined in ETSI/RRS TR 102 684).
Information detail levels

- **Root**: Information
- **1st level of detail**: e.g. Profiles etc.
- **2nd level of detail**: e.g. Terminal Profile etc.
- **3rd level of detail**: e.g. Communication Capabilities etc.
- **4th level of detail**: e.g. Network Interface etc.
- **5th level of detail**: e.g. Parameter/ Data type detail
Indicative $C^4$MS data structures: Overview

- Profiles
  - Node Profile
  - User Profile

- Context
  - Network Context
    - BS Context
    - Terminal Context
  - Node Context

- Policies
  - Network Operator Policies

- Decisions
  - ON Decisions
    - Infrastructure Decisions
  - Decisions

- Knowledge
  - Network Context
  - Node Context
  - Decisions
Indicative C⁴MS data structures: Profile information (1)
Indicative C⁴MS data structures: Profile information (2)

- **Terminal_Profile**
  - General Capabilities
    - Node_ID
    - Node_Type
    - Localization_Support
    - Display_Resolution
  - Communication Capabilities
    - Network_Interface_Capabilities
      - Interface_ID
      - RAT_Capabilities
        - RAT
        - Spectrum_Parameters
          - Spectrum_Block
            - Central_Frequency
            - Bandwidth
        - Transmission_Parameters
          - Transmission_Power
          - Maximum_Supported_Velocity
          - Maximum_Capacity
          - Spectrum_Aggregation_Capability
    - Supported_Sensing_Techniques
      - Detector_Types
  - Computing Capabilities
    - CPU_Frequency
    - Memory_Size
  - Storage Capabilities
    - Cache_Size
  - Energy Capabilities
    - Battery_Capacity
- **BS Profile**
  - Communication Capabilities
  - Network Interface Capabilities
    - RAT Capabilities
      - Spectrum Parameters
      - Transmission Parameters
  - Computing Capabilities
    - CPU Frequency
    - Memory Size
  - Storage Capabilities
    - Cache Size
  - Energy Capabilities
    - Battery Capacity
- **User Profile**
  - Communication Capabilities
  - Computing Capabilities
  - Storage Capabilities
  - Energy Capabilities
- **Operator Profile**
  - Operator Profile
    - Operator_ID
    - Operator_Name
    - Infrastructure Elements (equipment that the operator owns/manages)
    - Subscribers
  - ON Capabilities
    - ON Support
    - Routing And Relaying Support
    - Multiple Connectivity Support
    - Network Coding Support
    - Caching Support
    - Number of Participations in ON
    - Remote Connection Setup Support
    - Media Streaming Support
    - Incentives
      - Incentive Type
    - Gateway Support

Incentive Type
Indicative C⁴MS data structures: Profile information (3)

- User_Profile
  - User_ID
  - User_Class_ID
  - ON_User_Preferences
  - Multimedia_Preferences
    - Video_Preferences
      - Video_Genre
    - Relaying_Interfaces
    - Subscribed_Applications
      - Application_Profile
        - Application_ID
        - Application_Name
        - Application_Type
  - User_Class
    - User_Class_ID
    - Quality_Level
      - Quality_ID
      - Utility
        - Utility_Value
        - Bitrate
        - Latency
        - Jitter
      - Cost_Information
        - Cost_Value
  - Behavior_Aspects
    - Number_of_Requests
    - Usage_Characteristics
      - Estimated_Session_Duration
      - Estimated_Data_Volume_Transfer
Indicative formulas for analytical signaling evaluation

Considered formulas

- The “BS/Terminal_Profile” data structure uses as arguments
  - the number of available interfaces that could be potentially used for relaying and
  - the number of available RATs per interface

\[
BS/Terminal\_Profile = 35 + \sum_{i=1}^{a} (18 \cdot x_i + 1)
\]
where
\[
a = \text{number of interfaces, } a \geq 1
\]
\[
x = \text{number of RATs (per interface), } x \geq 1
\]

- The “User_Profile” data structure uses as arguments
  - the number of available interfaces that could be potentially used for relaying
  - the number of subscribed applications
  - the user classes of each application and
  - the number of available quality levels for each user class

\[
User\_Profile = 26 + a + \sum_{i=1}^{\text{apps}} (9 + 12 \cdot q_i)
\]
where
\[
a = \text{number of interfaces, } a \geq 1
\]
\[
\text{apps} = \text{number of subscribed applications, } \text{apps} \geq 1
\]
\[
q = \text{number of quality levels, } q \geq 1
\]
Signaling evaluation – Estimation of data structure sizes

- Example sizes of data structure for different test cases

- BS/Terminal Profile

<table>
<thead>
<tr>
<th>Case</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
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- User Profile

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<th>4</th>
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<tbody>
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<td>3</td>
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<tr>
<td># Subscribed Applications</td>
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<td>3</td>
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<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
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<td># Quality levels</td>
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<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
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</table>
Indicative C⁴MS implementation

- RAT-independent implementation
  - IEEE 802.21 based
  - Distributed Agents based
IEEE 802.21 based implementation

- **IEEE 802.21 protocol header format**

```
0                   1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version|A|S|U|M| FragmentNbr |r| MIH Message ID |
|       | | | | |             | | SID | Op| AID |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|r r r r| Transaction ID        | Variable Payload Length |
|       |                       |                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

- **IEEE 802.21 parameter format**
  - Parameters are encoded in the Type-Length-Value (TLV) format as shown below:

```
0                   1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Type         | Length (of V.)|    Value                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       ...                                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

**Example how message is created and sent over the C4MS-API:**

```java
C4MSMessage indicationMsg = new C4MSMessage(MSG_ID_ON_Suitability_IND);
indicationMsg.addTLV_Source_MIHF_Id(getLocalHostAddress());
indicationMsg.addTLV_Destination_MIHF_Id(getTargetNodeostAddress());
indicationMsg.addTLV_CellDescriptor(potentialCell);
...
c4msClient.doSendMessage(indicationMsg)
```

**Trace of the message over the external interface:**
```
** Transmitted: 104 Bytes over TCP/IP
10 00 34 c0   *C4MS Header, MIH Msg ID: ON_Suitab.IND
00 08 00 60   *C4MS Header, Payload Length: 96
01 0d         *TLV Source_MIHF_Id 149.204.84.66
31 34 39 2e   *TLV Dest_MIHF_Id 149.204.84.119
32 30 34 2e   *TLV Type 241: Cell-Descriptor (Grouped)
38 34 2e 36   *TLV Access-Network-Id
31 39         *TLV Cell-Id
a0 07         *TLV Link-Type
a4 04         *TLV Cell-Capacity
64 64 64 64   *TLV Geographical-Position
8c 08         *TLV Cell-Radius
b1 14         *TLV Freq-Supported
```
Distributed Agents based implementation (1)

- FIPA-compliant ACL messages transmitted
- Indicative message structure:

  (QUERY-IF :sender ( agent-identifier :name CMON_BS_16@83.212.238:1077/JADE :addresses (sequence IOR: )) :receiver (set ( agent-identifier :name CMON_4@83.212.238:1077/JADE :addresses (sequence IOR: ))) :content "((SEND (ON_CreationRequest : ....))))" :language fipa-sl :ontology C4MS)
Distributed Agents based implementation (2)

- Indicative messages exchanged through the middleware platform (JADE) which realizes the distributed agents implementation

-ON_Creation.Request transmitted through the OM interface (between CMON-CMON)

-ON_Creation.Answer transmitted through the OM interface (between CMON-CMON)
The following algorithms have been defined:

- Fittingness factor-based spectrum selection
- Modular decision flow approach for selecting frequency, bandwidth and radio access technique for ONs
- Machine learning-based knowledge acquisition on spectrum usage
- Techniques for aggregation of available spectrum bands/fragments
The following solutions have been defined:

- Discovery of terminals supporting ONs
- Triggering of suitability determination
- Knowledge-based suitability determination and selection of nodes and routes
- Route pattern selection in ad hoc network
- Multi-flow routes co-determination
- QoS and Spectrum – aware Routing Techniques
- Techniques for network reconfiguration – topology design
- Application cognitive multi-path routing in wireless mesh networks
- UE-to-UE Direct Path
- Content conditioning and distributed storage virtualization/aggregation for context driven media delivery
- Capacity extension through femtocells
- Dynamic exploitation of simultaneously operated links to multiple heterogeneous RATs
Validation activities

- Proof-of-Concept Architecture
- Developed demonstration focus areas
  - 1st focus area: Spectrum – Knowledge based spectrum selection
  - 2nd focus area: Selection of nodes and routes
  - 3rd focus area: Infrastructure supported opportunistic networking/ Direct D2D communication
Validation activities: Proof-of-Concept Architecture

User Data Flow | C4MS Flow | Transport Techno | Building Block
--- | --- | --- | ---
Device-to-device Application | CMON & CSCI | JRRM, CCM | 3G RAT | WiFi RAT
Device-to-device Application | CMON & CSCI | JRRM, CCM | 3G RAT | WiFi RAT

ON-enabled Mobile Devices

WiFi AP Infrastructure

Femto AP Infrastructure (also mimicking macro AP)

ON Manager

Public mobile network & Internet

3G

WiFi

LAN

DSM, DSONPM

CMON & CSCI

JRRM, CCM

3G RAT

WiFi RAT
Validation activities: Developed demonstration focus areas (1)

- 1st focus area: Spectrum – Knowledge based spectrum selection

Functionality for spectrum opportunity identification and selection
Validation activities: Developed demonstration focus areas (2)

- **2nd focus area: Selection of nodes and routes**

Selection of nodes and routes in the wireless access

Selection of nodes and routes in the backhaul
Validation activities: Developed demonstration focus areas (3)

- **3rd focus area: Infrastructure supported opportunistic networking/ Direct D2D communication**

  - **Content Sharing Application**
    - CMON
      - JADE agent
      - ON state machine
    - WiFi
      - Modified Android API for WiFi configuration
  - **User & session Management**
    - SIP Server, ensuring authentication and session management
  - **DHCP server**
    - Allocate IP address to equipments connected to the local LAN (Femto, Server)
  - **Debug tool: Wireshark**
  - **ON Manager (CMON)**
    - AP/Channel algo
    - JADE server
    - ON state machine
  - **Test SIM card**
    - Test SIM card is registered
    - Operating channel is authorized and interference level is minimal
  - **Femto AP**
  - **Ethernet**
  - **IP Switch**
Overall benefits and conclusions

- Definition and evaluation of data structures in order to support control channels

- Availability of pertinent implementations (research prototypes) which can be used for further studies related to C^4MS

- Studies could be based on related scenarios as defined in RRS and OneFIT (e.g. Discovery and identification of neighbouring devices and services; Opportunistic coverage extension; Opportunistic capacity extension etc.)

- Development of associated algorithms in order to support and evaluate the studies

- Validation and prototyping of the proposed work

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