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# コグニティブ無線システムにおける複数経路同時接続同時通信のための接続方式およびルーティング方式

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**あらまし**　次世代のモバイル端末は，セルラー網や無線 LAN，WiMAX など多種多様な複数の無線通信デバイスが利用可能になることが予想される．このようなモバイル端末において，それら複数の無線通信デバイスを用いて複数の通信経路を構築し，それらを同時に利用することで通信帯域を拡大することが可能である．しかし，無線資源は有限であるため，周波数有効利用と帯域拡大を同時に実現するのは非常に困難である．このような問題を解決する技術としてコグニティブ無線が提案されている．本稿では，コグニティブ無線において，複数経路同時接続と同時通信を可能にする接続方式，およびルーティング方式を提案する．同時に，それらの実現に必要なアドレッシング方式とその有用性について述べる．

# Multihomed Routing and Multimode Access in Cognitive Wireless Systems

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**Abstract**　It is expected that future generations of mobile devices will be equipped with multiple wireless access interfaces. Such mobiles will be able to concurrently use their multiple wireless interfaces, such as cellular, WLAN, and WiMAX for simultaneous data transmission. However, improving both spectral efficiency and bandwidth is a new challenge for wireless access networks using mobile devices with multiple wireless access interfaces. This paper outlines a cognitive wireless system (CWS) that provides multimode wireless access and uses multihomed routing functions for spectrum efficient routing. Multihomed routing allows the distribution of several flows via different multiple wireless interfaces between the access terminal and the cognitive base station (CBS). The advantages of using multiple home addresses (MHoA) and multiple care-of addresses (MCoA) in CWS are presented.

**Keywords**　Multihomed Routing,　Multimode Wireless Access,　Wi-Fi,　WiMAX

## 1. Introduction

Future Wireless LAN access points and wireless access terminals, such as PDAs or mobile phones, will provide more than one active wireless link for simultaneous data transmission. New technologies for so-called link aggregation to combine different wireless links increasing the bandwidth or improving access reliability are still under development. However, a demand to combine multiple wireless interfaces in a more dynamic way can be identified for next generation wireless networks, which will provide a intelligent routing and efficient utilization of the radio spectrum using a cognitive wireless system (CWS) that is frequently monitoring the surrounding radio spectrum [1].

This paper presents a CWS communication system where multiple wireless interfaces are used simultaneously, improving the available bandwidth. This system provides so-called multihomed access via multiple wireless interfaces. The multihomed access is based on the concurrent use of multiple wireless interfaces, both at the access terminal (AT) and at the cognitive base station (CBS). Mobile IP (MIP) has been identified as a candidate to provide global access while the terminal is roaming among different IP domains. However, MIP was standardized by the assumption to have only one wireless interface at the terminal and the point of attachment. Thus, a discussion is needed how multihomed access can be realized for the CWS system.

The paper is organized as follows. Section 2 shows the overview of the cognitive wireless system using multiple interfaces. Section 3 gives an introduction about multiple interface support and wireless multimode access. Section 4 outlines the multimode CWS reference architecture. A detailed routing fabric is presented in section 5 and an example for load balancing and flow distribution in CWS is presented in section 6. The conclusion is discussed in section 7 and the outlook of the future research is given in section 8.

## 2. Overview of Multihomed Cognitive Wireless System

The demand for multihomed wireless access is still increasing. This fact can be observed by implementing different kinds of new wireless technologies supporting higher bandwidth, such as IEEE 802.11a/b/g. Current Wi-Fi technologies are offering higher bandwidth using efficient modulation and coding schemes. Moreover, it can be observed that there is a demand for wide area broadband wireless networks which offer both, high bandwidth and wide area access. The WiMAX forum [2] is working on standardizing multiple IEEE 802.16 modes and finalized a first draft, where different frequencies

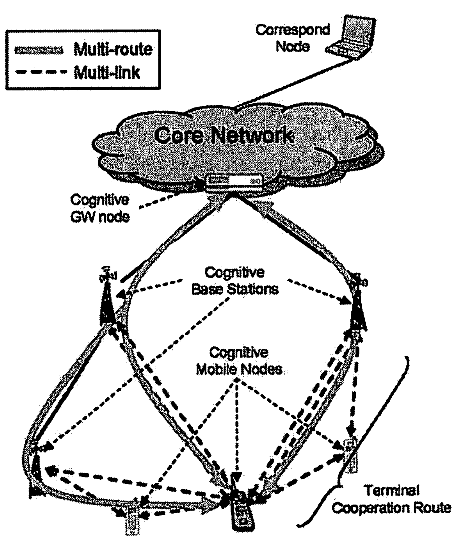


**Figure 1: Cognitive Wireless System (CWS)**

will be selected (2-66 GHz) depending on the scope of the usage [3], [4].

For next generation wireless networks, the integration of Wi-Fi and WiMAX can be seen as a logical step for bandwidth improvement and wireless ubiquitous access. Wi-Fi allows narrow area communication with moderate bit rates (hot spots), and WiMAX offers wide area access with sufficient bit rates for mobile wireless access. Moreover, the integration of both wireless technologies allows communication scenarios which will fulfill future requirements of mobile users, such as high wireless access reliability, broadband access, guaranteed QoS and ubiquitous wireless connectivity.

Fig.1 shows the topology of a generic cognitive wireless system (CWS). The system contains a cognitive gateway (CG) and cognitive base stations (CBS) which are attached to the CG. The CG acts as a gateway between the cognitive access network and the Internet. It also aggregates information about the short-term and long-term behavior of the network which can be used for adaptive flow decisions in the CWS. This is required to reduce signaling and to use an adaptive radio channel assignment for spectrum efficient data transmission.

Efficient spectrum usage is realized through simultaneous use of multiple wireless channels, identifying free and congested channels and shifting communications among channels to reduce congestion while improving the overall bandwidth.

Coverage is extended by using multihop communication between the access terminals (AT). Each AT which is in coverage of a hot spot can act as a wireless router for adjacent wireless access terminals which are outside of the coverage of the hot spot.

## 3. Multiple Interfaces and Multimode Access

Multiple interfaces at the access terminal allow simultaneous access to the CBS. But there are more advantages when a mobile nodes is equipped with multiple interfaces. The use of multiple interfaces allows

- Prioritized load balancing and flow distribution between different kind of wireless technologies, such as Wi-Fi and WiMAX.
- Reduction of packet loss while switching data flows between different WLAN technologies (interface mobility).
- Backup interface setup when one active interface is out of coverage or not available for data transmission (broken, unplugged, congested).

In this study the flow distribution is the most important feature. For instance, to spread a data flow which consists of two different types of data, data with high priority can be forwarded via interface with high reliability and always on connectivity, such as WiMAX, whereas data with low priority and high probability of packet retransmissions can be forwarded via Wi-Fi interfaces. However, the routing needs the information how to access the interfaces for flow distribution. Thus, the care-of address (CoA) plays an important role.

In a scenario where the AT is equipped with multiple interfaces, IF#1, IF#2, and IF#n, each interface needs its own IP address. This is needed to spread the flow via different points of attachment, for instance CBS 1 and CBS2, while IF#1 is connected to CBS 1 and IF#2 is connected to CBS2. The two interfaces belong to different IP domains and require different CoAs. This is where multiple CoAs are defined for access terminals with multiple interfaces. Note it is also possible to have one IP address available for different wireless interfaces. The bonding feature in Linux [9] provides bonded interfaces, while mapping the different MAC addresses into one logical interface.

Multiple care-of addresses (MCoA) and multiple home addresses (MHoA) are not standardized for MIPv4 [10] or MIPv6 [11]. However, there is an ongoing discussion at the IETF to standardize MCoA and MHoA in the near future [14].

Multihomed access is based on the use of multiple wireless interfaces. But the definition of wireless access in CWS contains more than only multihomed access. The CWS also uses multihop communication to extend the coverage of WLAN hot spots and to build up routes which fulfill the demand for spectrum efficiency. There is also the possibility to use different paths simultaneously while using different wireless channels reducing interference between data flows. These different kind of wireless access methods lead into a new definition of so-called multimode wireless access. Multimode access can be defined as access via

- multiple interfaces
- multiple hops
- multiple paths or links
- multiple channels or frequencies

Fig. 2 shows an access terminal which is attached to different CBS. Each interface uses different CoAs and different wireless channels. This AT can also work as a router for its neighbors using multihop communication.

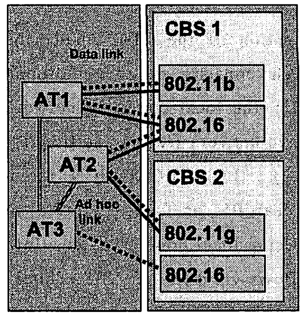


**Figure 2: Multimode Access in CWS**

This is how multimode access in CWS works, the utilization of different wireless links and channels to improve the wireless bandwidth and reducing the spectrum interference.

In the following the multimode concept is discussed based on a Mobile IP architecture.

## 4. Multimode CWS Reference Architecture

Regarding the requirement for efficient routing in CWS several candidates for mobility support and multiple interface access have been identified. Mobile IP allows seamless mobility with a reduced link disruption during movements. Mobile IP provides an architecture that consists of the home agent (HA) which keeps the current position (binding) of the access terminal. Beside the HA, so-called foreign agents (IPv4) or foreign routers (IPv6) are required to provide the detection of the access terminal within foreign networks. Mobile IPv4 and Mobile IPv6 are standardized and extended features such as hierarchical Mobile IP [12] and Fast Mobile IP [13] are currently under development at the IETF extending the performance of Mobile IP (MIP).

The use of MCoA and MHoA allows the distribution of different data flows, while the routing is based on a table which contains the current binding of each interface address inside the binding table of the mobility anchor point (MAP) [12] or global home agent. The concept of the MCoA is currently discussed at the IETF [14]. It will be necessary to standardize the routing for MCoA with the consideration that future terminals will be equipped with multiple wireless interfaces.

In CWS the system architecture can be build up as a core network which consists of local home register (LHR) which act as local home agents or MAP in MIPv6. Fig. 3

shows the location of the LHR inside the CWS core network, which consists of the multimode cognitive network (MCN), the local cognitive network (LCN), the remote cognitive network (RCN) and the global cognitive network (GCN). LCN, RCN, GCN provides a home register for local BU or the global BU for the GCN, respectively. Using local home register allows the control of local data flows via different CBS. This is an essential function that is needed for flow distribution via different point of attachments and different interfaces at the AT.

The LCN provides the multimode access that includes the wireless access using different interfaces, different wireless channels and a route selection via different hops. Thus, a switching function has to be implemented for interface and channel selection. Note that the access point and the AT need at least one fixed channel for communication. Moreover all ATs in coverage of the CBS need at least one common channel for data or signaling information. Thus, the CBS cannot change the so-called master channel. Otherwise the connection to all different ATs will be broken. However, additional interfaces can be used in a manner that they can select independently the wireless channel to their neighbors (link-disjoint paths) and for multihop communication (node-disjoint paths) to fulfill the demand for reducing channel interferences.

The LCN contains different numbers of CBS depending on the total number of mobile users. To consider a high scalability of the CWS, the RCN connects the CBS for local flow distribution that is maintained by the CG. Several CGs can also be connected for a wide scale CWS network that is maintained by the GCN for global flow distribution and load sharing.

The reference architecture in Fig. 3 also includes a so-called bonding register. These bonding registers are needed to select available communication paths and

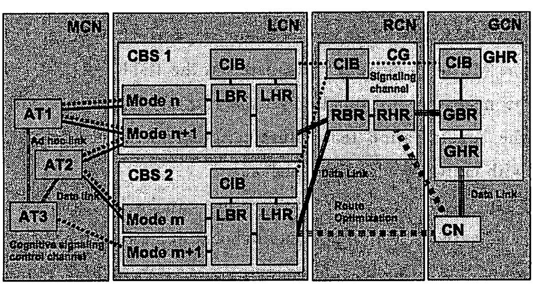


Figure 3: CWS Reference Architecture

interfaces for concurrent use and bandwidth improvement. Bonding features include the simultaneous use of different interfaces (different MAC addresses) providing one so-called logical bonded interface. The behavior of the bonded interface is mainly based on predefined modes, such as load balancing [9].

| | |
|---|---|
| AT | Access Terminal |
| MCN | Multimode Cognitive Network |
| LCN | Local Cognitive Network |
| RCN | Remote Cognitive Network |
| GCN | Global Cognitive Network |
| CBS | Cognitive Base Station |
| CIB | Cognitive Information Base |
| LBR | Local Bonding Register |
| LHR | Local Home Register |
| RBR | Remote Bonding Register |
| RHR | Remote Home Register |
| GHR | Global Home Register |
| CG | Cognitive Gateway |
| CBR | Global Bonding Register |
| CN | Correspondent Node |

**Table 1: List of acronyms for CWS**

The control of the local home register and the bonding register needs a function to select most appropriate links and interfaces for multimode communication. Thus, the cognitive information base (CIB), identifies the current status of the system and the radio spectrum to select interfaces and routes for spectrum efficient high speed data transmission. Interface and link status information, which are monitored at the AT or CBS are exchanged between the CIBs for short-term and long-term analysis of the entire CWS system.

## 5. Multihomed Routing

In the following the multiple interfaces support that is based on multiple CoA and HoA is presented while the routing is based on a preferred routing table for multihomed wireless routing.

### 5.1. Multiple Interface Support

To provide global mobility inside CWS each wireless interface needs to have its own HoA, which is a global routable IPv6 address. After leaving the home network the interface of the AT gets the CoA from the foreign network. The foreign network contains a router advertisement daemon that frequently sends agent advertisements. The advertisements are used at the AT for movement detection and configuration of the CoA. After the attachment to the new network the AT sends a binding update (BU) via the new interface to register with a new CoA and the HA. The BU has to be sent from the AT to the HA or the correspondent node (CN). The BU at the CN can be used for route optimization to avoid triangular routing via the home agents.

The home address of the AT is the IPv6 address inside the home network. This address is a global routable IP address. The CoA is the IP address of the new network. Also this IP address should be globally routable. This is due to the reason that CoA can also be used as a new home address (local home address) for efficient flow distribution. However this idea is part of the future work of this project.

## 5.2. Preference Routing Table

The AT needs additional routing tables to identify which interfaces are available for routing and which interface has the highest priority. Priority is needed to identify the policy for routing decisions. The AT needs a default (or preferred) interface for the main connectivity with the CBS. The default interface is used when there is no policy defined or other interfaces have the same priority or system characteristic. The default interface should be the interface that provides the highest throughput and the required QoS support, such as minimum delay, less jitter and high bandwidth. Additional interfaces are used when the default interface is not available or when there is a demand for load balancing via multiple interfaces. Thus, the choice of the interface defines the IPv6 address and its related HA that can be located on a neighbor access point (simultaneous use of multiple CBS).

Table 1 shows a definition of multiple interfaces related to their CoAs. In Tab. 1 the default interface IF#1 has CoA 1 that is a global routable IP address of the foreign attachement. However, the priority of that interface can be lower than the priority of other interface combinations. For instance, the next entry of the preference routing table contains a combination of two wireless interfaces, IF#1 and IF#2. If IF#2 is available as a second interface, e.g., for load balancing, this routing entry is used, because it has the highest priority (p=0.9) of all routing entries. A combination of IF#1, IF#2, and IF#3 may have a low priority, due to restrictions such as for the battery life of the AT.

| | Interfaces | MCoA | Priority |
|---|---|---|---|
| Default | IF#1 | CoA1 | Medium (p=0.7) |
| 1 | IF#1, IF#2 | CoA1, CoA2 | High (p=0.9) |
| 2 | IF#1, IF#2, IF#3 | CoA1, CoA2, CoA3 | Low (p=0.1) |

**Table 2: Preference routing table**

## 5.3. Simultaneous use of Wireless Interfaces

If there are different interfaces available the AT initiates flows with different HoAs or CoAs to use several interfaces simultaneously. In this case the AT is called as a multihomed MIPv6 node, defined as follows [15]:

*A node is said to be multihomed when it has multiple IPv6 addresses, either because multiple prefixes are advertised on the links the node is attached to, or because the node has multiple interfaces.*

A node operationg MIPv6 is said multihomed when it simultaneously has

- Multiple HoA
- Multiple CoA
- Single HoA and single CoA configured on different interfaces.

In the following a detailed description is given about the load balancing and flow distribution of a multihomed AT in CWS.

## 6. Load Balancing and Flow Distribution in CWS

Efficient load balancing and flow distribution in CWS requires the implementation of the required MIP support inside the system architecture. It also requires the design of the routing tables which uses MCoA and MHoA for multihomed routing in CWS. Figure 4 shows an example of flow distribution of the CWS system and includes an overview about all required routing tables. Figure 4 shows the routing table for the AT, the CBS, the CG, and the global HA. For the AT it can be identified that each wireless interface (IF#1, IF#2, IF#3) has its own CoA. There is also a difference between the CoA and the related HoA, because IF#3 is connected via second CG that is equipped with its own local HA. The CBS and the CG have local binding tables, related to the local address of the CBS and the home address of the AT.

Beside the different CoAs a separated flow at the global HA can be identified using different home addresses of the AT. The local HR (home register) at the CG keeps the current binding and flow distribution via different CBS (see flow 1), whereas a second flow is forwarded directly between HR2 and CBS3.

After changing the point of attachment, the routing entries change. In Figure 5 the changes of the routing entries can be identified. After changing IF#1 and IF#2 from CBS1 to CBS2 the binding at CBS1 becomes invalid.

A new BU is sent by the AT via the new CBS and

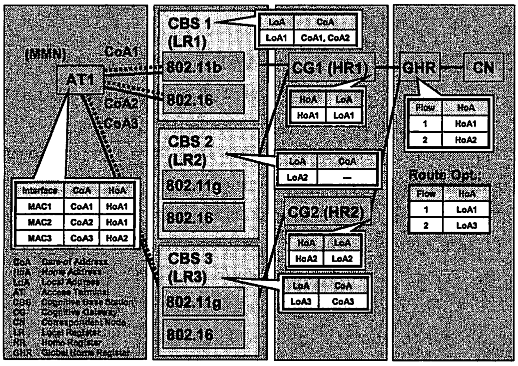


**Figure 4: Flow distribution via multiple CBS (example)**

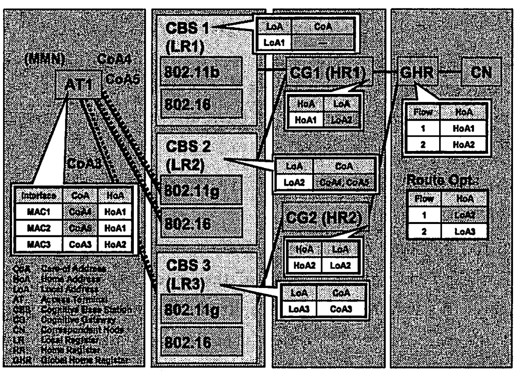


**Figure 5: Flow distribution after changing wireless point of attachment (example)**

becomes a valid binding at CG1. For the new binding entry the IP address of the CBS changed, from CBS1 to CBS2. Note that also the IP addresses changes at the AT, while keeping the MAC address of the wireless interfaces. For route optimization a BU can be sent directly to the CN. This can be identified that the routing entry for flow 1 changes from LoA1 to LoA2. After the new BU at all registers changes, the flows are redirected to the new location of the AT. To reduce packet loss during flow redirection, a hierarchical structure is used to avoid long link disruption between the AT and the CWS.

## 7. Conclusion

The concurrent use of wireless interfaces at mobile access terminals requires a network architecture that provides multihomed wireless access. Moreover, the cognitive wireless system in this study also provides multimode access, via different interfaces, wireless channels and multihop paths. MIPv6 and its extension for MCoA and MHoA allow an efficient flow distribution for multihomed access terminals.

## 8. Future Work

Future work will consider an implementation of MIPv6 and HMIPv6 for CWS with an intelligent decision making for bandwidth improvement and efficient use of the radio spectrum.

## 9. Acknowledgment

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