Virtual residential gateways: Architecture and performances

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***Abstract*—With the increase of the transmission bit rate on optical fibers, it is now possible to transmit a base band signal over long distances. A very promising technology called Digital Radio Over Fiber (DRoF) uses this principle and allows centralization of resource management in the base stations architecture. This architecture is consist of three components: a Base Band Unit (BBU), a Remote Radio Head (RRH) and the interface between them such us CPRI (Common Public Radio Interface). In this paper, we propose to use the DRoF technology to virtualize current residential gateways making them less complex and allowing centralization of resources management. We show however that the propagation delay can be a serious problem for WiFi as we increase the distance between terminals and the access point. We use then an analytical tool called Bianchi Model to evaluate the performances.**

I. Introduction

In the last decade, high bit rates availability and competitive ISP (Internet Service Providers) offers have considerably increased the number of internet subscribers. To access the internet, those subscribers use generally a special device known as ”residential gateway” (RGW) which is connected via an xDSL connection to the ISP network. A RGW is mainly composed of an Ethernet card and a WIFI access point to provide both wired and wireless access, it also includes an IP router with all common features such as DHCP and DNS servers that needs to be configured. Even if default configurations are set by the operators, the customer is often lost when he needs to do some modifications.

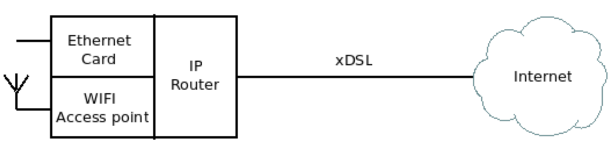

Fig. 1. Current residential gateway

To deploy devices as simple as possible in the customer premises, we propose to use the DRoF (Digital Radio Over Fiber) technology in order to virtualize RGWs. Also, as the RGW is a router, it was necessary that all the local traffic is contained in the local network. This was necessary when the access bit rate was limited to several Mbps. With the deployment of FTTH (Fiber To The Home), customers can benefit from data rates up to several Gbps.

In a DRoF architecture [1], the access point is splitted into two parts: a Remote Radio Head (RRH) close to the antenna and a Baseband Unit (BBU) that can be hundred of meters from it. This is possible thanks to the high bit rate offered by optical fibers making possible the transmission of baseband signals over long distances. In the downlink (the inverse process is done in the uplink), the BBU generates symbols from the digital baseband signal which is consist of an in-phase (I) and a quadrature (Q) components. The signal is then sampled, quantified, modulated and transmitted over the fiber to the RRH wich is in charge of the frequency shifting. Of course, the use of a special interface between BBU and RRH, namely CPRI, is necessary.

Using the DRoF technology, it is then possible to split the WIFI access point into a RRH that will stay in the gateway and a BBU that can be shifted to the ISP network. To make the Virtual Residential Gateway (vRGW) even less complex, we propose to shift the IP router also to the end of the ISP. Centralizing all features in the ISP network will also allow a better resources allocation control and make the management easier.

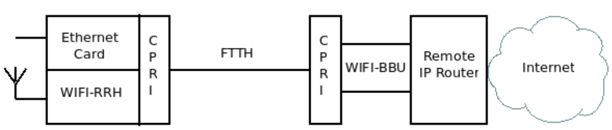

Fig. 2. Virtual residential gateway (vRGW)

The reminder of this paper is organized as follow. In section II we present briefly the CPRI interface. Section III describes the use of the CPRI interface in the virtual residential gateway. Then section IV shows how WIFI traffic can be transported over CPRI. Section V eventually concludes this paper.

II. CPRI overview

[2] CPRI is an industry cooperation which defines the specifications for the interface between the RRH and the BBU. The specification defines only the protocols for layer 1 (physical layer) and layer 2 (data link layer) making it restricted to the link interface.

The transmission in CPRI is organized in frames. A typical CPRI frame is consisted of 1 control word (CW) used for control and management, and of 15 data words transporting the IQ user data. A word can be coded in 1 byte, 2,...up to 16. Each word is always an integer number of bytes but transferred with 8B/10B coding. Consecutive control words produce a channel used for control, management and synchronization. As CPRI was proposed for UMTS in the first place, the frame rate is equal to the UMTS chip rate: $T_c = 1/3.84\text{MHz} \approx 260\text{ns}$.

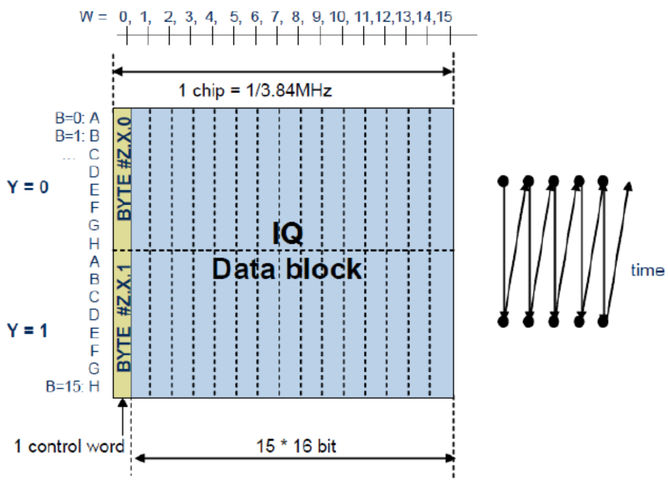

Fig. 3. One typical CPRI frame composed of two bytes words

The BBU generates modulation symbols with a sampling frequency f_s. These samples, which are consist of M bits per component (I or Q), are then packaged into a so called AxC Container (Axc: antenna carrier). A typical AxC container is composed of a part of or several IQ samples depending on the mapping method used; let N_{AxC} be the AxC container size which is required to always be an even number. AxC container are then mapped in the IQ data block of the CPRI basic frame.

IQ mapping method

For systems other than UMTS, the sampling frequency (f_s) is not always equal to the CPRI frame frequency ($f_c = 1/T_c$). The number of bits per frame is then equal to: $2Mf_s/f_c$, note that this is not always an integer number. To be sure that all AxC containers have the same size, the specification defines the concept of AxC container block which spans over the minimum number of CPRI frames K such that it includes an integer number of samples S. K and S are defined by:

$$K = \frac{LCM(f_s, f_c)}{f_s} \tag{1}$$

$$S = \frac{LCM(f_s, f_c)}{f_c} \tag{2}$$

where LCM stands for Least Common Multiple.

1) Mapping method 1 (IQ sample based): This mapping method requires that a AxC container contains an even number of bits, N_{AxC} is then given by:

$$N_{AxC} = 2\lceil \frac{Mf_s}{f_c} \rceil. \tag{3}$$

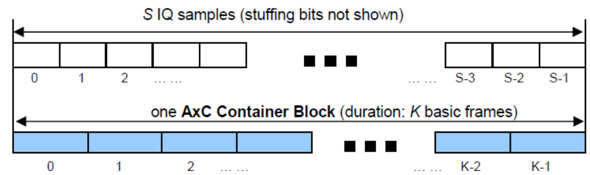

Fig. 4. Relation between S samples and one AxC container Block

Note that it is possible to have several IQ samples or a part of a sample within one AxC container. As the number obtained is rounded up, there is still some unused bits when the AxC container is mapped into the frame. This unused space is filled with stuffing bits that are placed in the beginning of the AxC container block. To know how many stuffing bits are necessary, we can use:

$$N_{ST} = KN_{AxC} - 2MS. \tag{4}$$

2) Mapping method 2 (Backward compatible): In this mapping method, an AxC container contains one IQ sample only, its size is then equal to the sample size: $N_{AxC} = 2M$. However, it is now possible to group several antenna carriers (AxC) with the same sampling frequency and the same sample width in a so called AxC Container Group. Let N_A be the number of AxC in one AxC container group. The AxC IQ samples are then multiplexed into a AxC container block consisting of N_C AxC container per basic frame, so N_AS samples. In order to minimize the number of stuffing bits, the number of AxC container per CPRI frame is calculated with:

$$N_C = \lceil \frac{N_AS}{K} \rceil. \tag{5}$$

The number of stuffing bits per AxC container block is given by:

$$N_V = N_CK - N_AS. \tag{6}$$

III. CPRI INTERFACE IN VIRTUAL RESIDENTIAL GATEWAY

As we have seen in Fig. 2, a vRGW includes a WIFI and an Ethernet interface. The traffic generated by both of them is transported through the CPRI interface. For that, we suppose that the CPRI frame is divided into two parts: the first one is allowed to WIFI traffic while the remaining space carries Ethernet frame.

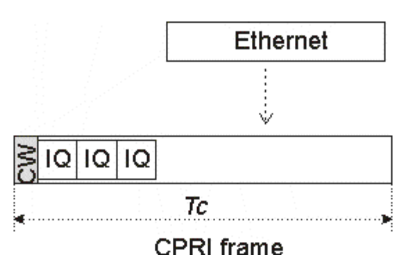

Fig. 5. Mapping Ethernet frame in the CPRI frame

RGWs Ethernet interface is often a 1Gbps interface, but can in some cases be only a 100Mbps interface. Hence, to be able to transport the Ethernet traffic over CPRI, it is necessary that the remaining capacity is at least equal to the Ethernet interface bit rate.

IV. WIFI OVER CPRI

As we presented before, CPRI acts as the interface between WIFI-RRH in the vRGW and the BBU in the ISP side. In this section, we show how to transport WIFI over CPRI using methods presented in II. Due to its popularity, all our study is about IEEE 802.11g but can be adapted to other standards.

First of all, let us notice that the 802.11g sampling frequency is 20MHz [3] which is different from the CPRI frame frequency 3.84MHz II. In this case, it is necessary to compute the AxC container block size K and the number of samples S it contains. By using (1) and (2), as $f_s = 20$MHz and $f_c = 3.84$MHz, we thus have $K = 24$ and $S = 125$.

To compare the use of the two mapping methods with WIFI, we calculate the number of vRGWs that can be supported depending on the CPRI line bit rate. We also calculate the unused bit rate. As seen in III, this unused bit rate can be used to transport Ethernet traffic.

A. mapping method 1

We first compute the number of unused bits per CPRI frame, which is equal to the useful bits N (bits allowed to IQ data) per frame minus the number of unused bits:

$$N_b = N - N_{AxC} N_G. \tag{7}$$

The unused bit rate is then equal to $3.84 N_b$Mbps.

N_{AxC} is the AxC container size given by (3), and N_G is the number of AxC groups. We suppose that an AxC group contains samples from only one AxC, so N_G can be seen as the number of vRGWs. Using the fact that N_b have to be greater than or equal to 0, it is possible to compute the maximum number of vRGWs:

$$N_G \leq \frac{N}{N_{AxC}} \Leftrightarrow N_G = \lfloor \frac{N}{N_{AxC}} \rfloor. \tag{8}$$

B. mapping method 2

Using the same reasoning, we can compute the number of unused bits with:

$$N_b = N - N_{AxC} N_C \tag{9}$$

While an AxC container is consist of only one IQ sample, N_{AxC} is equal to the sample size $2M$. N_C is the number of AxC container per CPRI frame and according to (5), it is equal to $\lceil \frac{N_A S}{K} \rceil$. As it is possible in this method to have samples from several AxC container, N_A can be seen as the number of vRGWs.

Like we said in III, the unused bit rate can be used to transport Ethernet traffic. Hence, it is necessary that the remaining capacity is at least equal to the Ethernet interface bit rate. The following tables show, for the two mapping methods, the maximum vRGWs that can be supported depending on the line bit rate, and taking into consideration the LAN interface rate. The first column "mode" is the possible words sizes in the CPRI frame. The second one is the CPRI line bit rate we consider, "IQ bit rate" is the unused rate and "available bit rate" is calculated using (7) or (9). The last column is the bit rate allowed to each vRGW and has to be at least equal to the interface rate (Ethernet min rate).

mode	Bit rate (Mbps)	nb AP	IQ bit rate (Mbps)	Available bit rate (Mbps)	Eth min rate (Mbps)	Eth rate / AP (Mbps)
1	614,4	1	322,56	138,24	100	138,24
2	1228,8	2	645,12	276,48	100	138,24
4	2457,6	1	322,56	1520,64	1000	1520,64
5	3072	1	322,56	1981,44	1000	1981,44
8	4915,2	2	645,12	3041,28	1000	1520,64
10	6144	3	967,68	3640,32	1000	1213,44
16	9830,4	5	1612,8	5760	1000	1152

Fig. 6. Number of possible RGWs for different line bit rate (Mapping method 1)

mode	Bit rate (Mbps)	nb AP	IQ bit rate (Mbps)	Available bit rate (Mbps)	Eth min rate (Mbps)	Eth rate / AP (Mbps)
1	614,4	1	368,64	92,16	100	92,16
2	1228,8	2	675,84	245,76	100	122,88
4	2457,6	1	368,64	1474,56	1000	1474,56
5	3072	1	368,64	1935,36	1000	1935,36
8	4915,2	2	675,84	3010,56	1000	1505,28
10	6144	3	983,04	3624,96	1000	1208,32
16	9830,4	5	1658,88	5713,92	1000	1142,784

Fig. 7. Number of possible RGWs for different line bit rate (Mapping method 2)

As we can see in Fig. 6, it is only possible to have a 100Mbps interface for mode 1 and 2. However, if we look at Fig. 7 we can see that for mode 1, the available bit rate is less than the minimum bit rate required. Thus, it is not possible to have even a 100Mbps interface for mode 1 when using mapping method 2. For the two methods, the maximum number of vRGWs is the same whatever the CPRI bit rate. We can see that method 2 gives a better IQ bit rate than method 1 but in the other side method 1 provides a higher rate for Ethernet interface.

However, we can notice that it is necessary for both methods to have a line bit rate almost equal to 1Gbps to support only 5 vRGWs.

C. Impact of the propagation delay

As we all know, IEEE 802.11 MAC layer uses a random access to the medium based on the carrier sense (CSMA/CA) mechanism [3]. This means that a mobile terminal wishing to send data needs first to listen to the medium during a period called DIFS [3], and can begin the transmission only if the carrier is free. However, if the propagation delay between two stations becomes too large they will not be able to sense the transmission of each other. More precisely, if station A is transmitting and the propagation delay to station B is larger than DIFS, B can believe that the medium is free and starts sending which will cause a collision. In other words, the collision probability is proportional to the propagation delay and so to the distance [4].

In our case, the fact that the BBU is moved to the end of the ISP increases considerably the propagation delay between the BBU and mobile terminals. Indeed, the transmission speed in 802.11 is approximatively equal to 3.0 x 10^8m/s, while it is equal in the fiber to 2.0 x 10^8m/s (supposing that the delay added by intermediary equipments is insignificant). The delay in the fiber is then reduced to $\frac{2}{3}\%$ of the radio propagation delay.

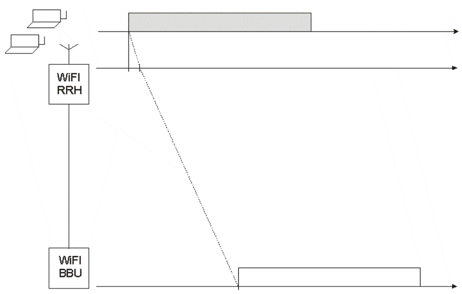

Fig. 8. Propagation delay in a virtual gateway Architecture

To evaluate the performances of WIFI in a such architecture, we use an analytic tool called Bianchi model [5]. However, several assumptions have to be made to be able to use the model.

First of all, it is supposed that there is a limited number of stations N and that the propagation delay between each pair of them is the same. The other key assumption is that each station operates in "saturation" conditions, which means that there are always a frame to be sent. This is a very strong assumption making the obtained performances undervalued. The different parameters we used for simulations are given in Table I below [4].

TABLE I. PARAMETERS FOR SIMULATIONS

Parameters	IEEE 802.11g
Transmission bit rate (Mbps)	54
MAC header (bytes)	34
ACK (bytes)	14
PHY Preamble + Header (bytes)	16+4
Slot time (s)	9
SIFS (s)	10
DIFS (s)	28
CW_{min}	16
CW_{max}	1024

CW_{min} and CW_{max} are the minimum and maximum contention windows given by:

$$CW_{min} = W_0 = W \tag{10}$$

$$CW_{max} = W_m = 2^m W \tag{11}$$

where W is equal to one time slot and m is the maximum back-off stage.

To evaluate the performances, we chose to look at the achieved throughput for a station in different situations. Actually, there are 3 main factors that can affect the throughput in a WIFI network: the number of stations, the distance between them and the payload.

In the first case, we fixed the propagation delay to 9s (1.8km through the fiber) and we varied the payload. We did this for different numbers of stations. In the other test, we fixed the payload to 1500 bytes and varied the propagation delay.

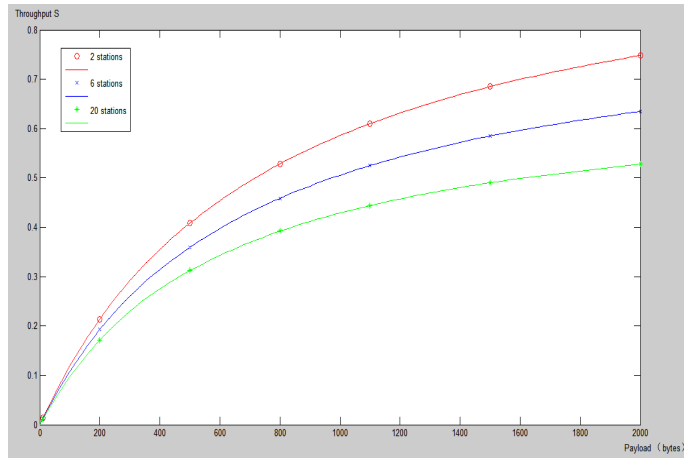

Fig. 9. Achieved throughput vs. payload

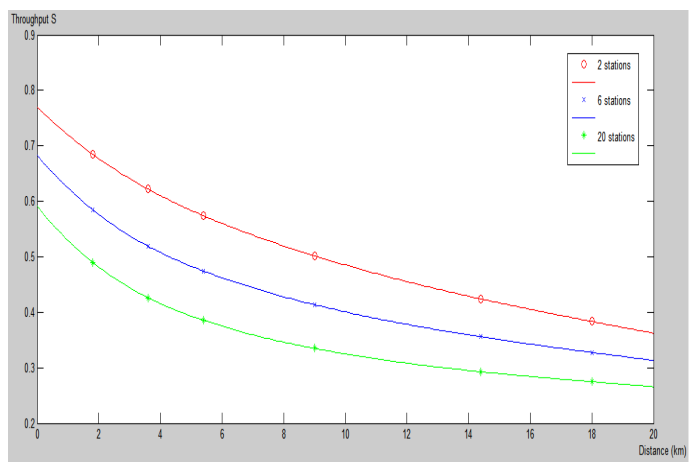

Fig. 10. Achieved throughput vs. propagation delay (distance)

Fig. 9 represents the results of the first test. It shows the achieved throughput when the payload increases when 2, 3 or 20 stations are sharing the medium. As it is expected, the throughput increases with the payload as more useful data are transported within one frame. However, the more the number of stations is the less the throughput is. This is due to the number of collisions which increases with the number of stations.

In Fig. 10, we can see the achieved throughput as a function of the distance. Note that the propagation delay can be obtained knowing that the transmission speed over the fiber is equal to

2.0×10^8m/s. As we can see the throughput decreases as the distance grows which is due to the increase of the number of collisions. Like the first case, the throughput decreases also when the number of stations grows.

V. Conclusion

In this paper, we proposed to use the DRoF technology to virtualize the residential gateways making them less complex and allowing an easier management and control of resources allocation. Using DRoF, we divided the residential gateways WIFI access point into two parts : a WIFI-RRH in charge of radio functions such as frequency shifting, and a WIFI-BBU where all control and management features are put. The WIFI-RRH stay in the gateway while the WIFI-BBU is shifted in the ISP network and can be hundred of meters from the gateway. This is possible thanks to high bit rates offered by the fiber allowing the transmission of a baseband signal over long distances.

We first presented the CPRI interface and how to use it to transport WIFI traffic. We used for that two methods described in the CPRI specification to map WIFI traffic into CPRI frames. We then compared the two methods in term of number of residential gateways that can be supported by one CPRI link. We also showed that the remaining capacity can be used to transport Ethernet traffic.

However, the fact that the BBU can be meters from the RRH increases considerably the propagation delay. And as known, in WIFI the collision probability increases with the propagation delay. To evaluate the performances of WIFI in a such architecture, we used a well none analytical tool called Bianchi model. We showed the relation between the achieved throughput and the number of stations, the distance and the payload which are the 3 main factors that can affect the throughput in a WIFI network. We confirmed that the number of stations and the distance are directly related to the number of collisions.

This was a first study where we presented that the virtualization of residential gateways is possible using the DRoF technology. This can be very beneficial for management and control of the resources allocation as all this functions are centralized. However, a lot of issues have to be considered such as the influence of the distance in WIFI networks and the very high bit rate that is necessary to support several gateways.

Acknowledgements

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