Extending IEEE 802.11 by DARPA XG Spectrum Management: A Feasibility Study

Mohammad M. Siddique[1], Andreas J. Könsgen[1], Carmelita Görg[1], Guido R. Hiertz[2], Sebastian Max[2]

[1]University of Bremen, Department of Communication Networks, Bremen, Germany
{mms|ajk|cg}@comnets.uni-bremen.de
[2]Aachen University of Technology, Chair of Communication Networks, Aachen, Germany
{grh|smx}@comnets.rwth-aachen.de

Abstract - **Increasing the spectral efficiency by opportunistic spectrum sharing among radios is the very recent research topic in the field of wireless communication. According to the report of SPTF about unused spectrum bands, the DARPA is investigating on opportunistic use of these unused bands in its XG communication program. In this paper, some options to use XG approach for the wireless systems, for example, for IEEE 802.11 or wireless local area network (WLAN) are shown. Different policy based XG parameters and respective 802.11 tunable parameters have been determined and the mapping among those parameters has been shown/analyzed. An extended structural model of the 802.11 radio system with DARPA XG communication is depicted with the help of policy and system conformance blocks and sensor. It can be concluded that, proper mapping of XG policies to abstract behaviors and controlling the radio according to polices, could increase the spectrum sharing opportunities and hence the spectral efficiency, for example, the throughput of the system.**

1. Introduction

Spectrum Utilization is becoming an important issue in the field of wireless communications (WC). Due to scarcity of spectrum band and deployment longevity of frequency dependent systems, the current conservative static method of frequency allotment is becoming a bottleneck in the proliferation of the wireless communication technology. However, it has been investigated (Spectrum Policy Task Force report) that large bands of allotted spectrum are unused both spatially and temporally [1]. This phenomenon is increasing due to more 'localization of propagation' as new services are working in higher frequencies and due to the development of highly bursty transmissions. This 'wasted spectrum' can be utilized intelligently by using the knowledge of the 'current spectrum situation' so that the available capacity can be improved. The Defense Advance Research Projects Agency (DARPA) neXt Generation (XG) communication program presents this intelligent spectrum access technology to the public. This is termed as opportunistic spectrum access technology and developing the opportunistic use of wasted spectrum both in space and time in such a way that interference will not disturb the primary (incumbent) user. For example, adaptive radio technique to use unoccupied TV-band [2].

The DARPA documents include the terms “policy” and “protocol” which are of major importance throughout all considerations. “Policy” means behavioral rules how a system should react to varying conditions inside the frequency spectrum which it is using. A policy can be, for example, a rule such as “if a TV signal is sensed on the current frequency, then the interference range must not be higher than 20 meters”. It is then up to the station how it actually implements this policy by using a protocol. In the above policy example, the station might check if it is possible to reduce the transmitter power to a level which meets the above criteria but is still sufficiently high to continue the communication with the partner station. Another option might be to switch to another frequency channel for which the policy given above does not apply. It can be seen that the policy is an abstraction of the actual protocol: the policy describes what has to be done, but not how to do it, which is performed by the protocol.

Another important term is “spectrum”. In this context, “spectrum” means any resource which is used or can be modified when performing a wireless communication; thus, it means not only frequency but also transmitter power, modulation scheme, channel bandwidth, channel allocation in the time domain, etc.

According to DARPA, the XG radio should be 'spectrum agile' as well as 'policy agile'. Spectrum agility is the ability to identify and select spectrum opportunities. This means the sensing mechanism has to find a channel where, on the one hand, the above-mentioned transmission resources are sufficient and on the other hand the own interference to the environment meets given constraints. These constraints are specified by policies which can vary dependent on the location (for example, the country where the device is used) and the time at which the station is operated. Even a combination of policies can be applied, for example an international policy given by a standard, a national policy given by a regulation authority and a local policy specified by the provider of a Wireless LAN hotspot. However, any of the policies can be changed any time. Policy agility is the ability to adapt to the currently valid policies which can be dynamically updated. In broader sense, the radios do not need to have a built-in policy; instead, this can be loaded 'on-the-fly'. The XG approach can thus be denoted as policy-controlled dynamic spectrum sharing. A station which has found a number of transmission opportunities has to validate which of them are suitable for the planned transmission. For example, a number of channels might have a sufficiently low interference level for the transmission, but according to a given policy some of the channels are reserved for voice telephony during business hours, while the station plans to start a file download.

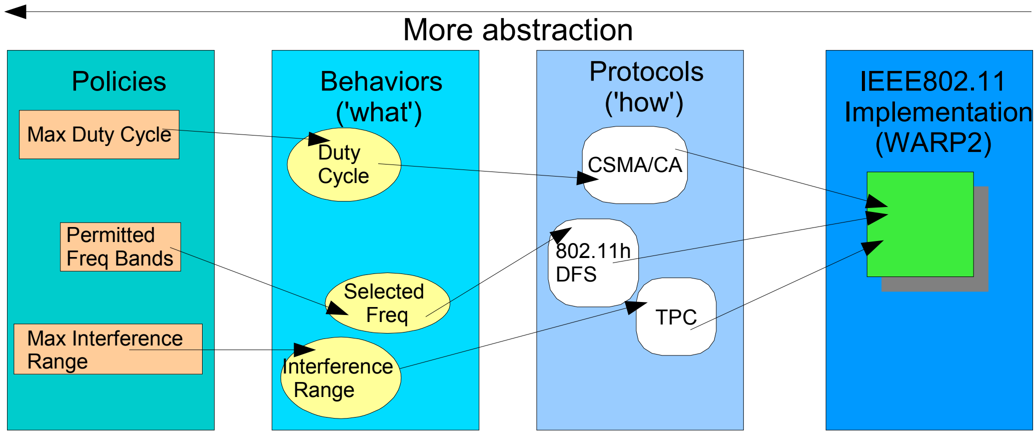

Figure 1: Decoupling of policies from behaviors and behaviors from protocols

2. XG Policy Agility

In traditional radio system operating policies are hard or soft coded with protocols and any change in policies would require re-design, re-implementation and re-accreditation. However, according to XG, a radio could be made policy agile by decoupling the policies from behaviors, behaviors from protocols and protocols from their implementations and these policies could be changed dynamically. To change the policies, radio should have the capability to read and interpret the spectrum policies (published by a spectrum authority) which are encoded in a machine interpretable form and can be loaded into the XG radio using smart media or over the Internet. The wireless local area network (WLAN)/IEEE 802.11 standard can be considered as an example. In the Figure 1, decoupling of policies, behaviors and protocols according to [1] for the XG radio has been shown in the case of IEEE 802.11 based radio model called Wireless Access Radio Protocol 2 (WARP2) [3, 4]. WARP2 is a stochastic discrete event simulator which investigates the different features of WLAN. More details over WARP2 will be described in later sections. Different protocols like IEEE 802.11a (CSMA/CA), IEEE 802.11h (DFS, TPC) have been implemented in this WARP2 simulator. The carrier sense multiple access with collision avoidance (CSMA/CA) is the fundamental access method of the IEEE 802.11 MAC, also known as distributed coordination function (DCF) [5]. The IEEE 802.11h describes mechanisms for dynamic frequency selection (DFS) and transmit power control (TPC) for Europe to satisfy regulatory requirements for their operation in the 5 GHz band [6]. A protocol performing its functionality can correspond to several behaviors. On the other hand, a single behavior might be implemented by a variety of protocols that might differ in algorithms. For example, in the Figure 1, duty cycle behavior can be adjusted by changing the DIFS length in CSMA/CA protocol. The upper limit of the duty cycle behavior can be controlled by the maximum duty cycle policy constraint. In this way, system behaviors can be adjusted or tuned according to the given constraints. Similar explanations can be given for other protocols, behaviors, and policies.

3. IEEE 802.11 and Radio Resource Management Extension

The IEEE 802.11h standard describes spectrum management methods to adjust two transmission parameters, namely the frequency and the transmit power. The specification of the standard includes the signalling for the channel sensing and to change the frequency resp. the power. In addition, the draft standard 802.11k, which is intended to support radio resource management strategies, specifies enhanced signalling for channel measurements compared with 802.11h. The standards do not define strategies or policies about the selection of transmit parameters, however they can be taken as a basis to provide the signalling between DARPA XG enabled 802.11 devices. Since DARPA XG includes any possible transmit parameter (besides the frequency and the power), extensions to the standard would have to be defined when deploying the standard for DARPA XG support. For example, 802.11h supports signalling to request a measurement of the C/I by a mobile station on a given channel. Considering the DARPA XG extension, it may be needed to add the bandwidth of the frequency range to be measured, since the XG supported system shall support variable bandwidths. Change the power and the frequency, which would have to be extended by signalling to change the number of OFDM subcarriers to adjust the utilized bandwidth. A further extension of the 802.11h standard would have to be signalling to download policy rulesets from another station. In legacy 802.11/.11h stations, the policies are hardcoded into the protocol stack and are not changed during the operation so that this problem is not considered in the original standard.

4. DARPA XG Policy Parameters

There are several transmit parameters that can be adjusted according to the DARPA XG policy framework. Following are some of them

- **Frequency (Channel Number):** When unlicensed channel/band is busy for a particular XG enabled device, then it may check sequentially the licensed spectrum channels (inside the specified frequency band) according to the policy for transmission availability.
- **Sensed Power Level:** When the sensed signal power level or receiver sensitivity for a specific channel is lower than a threshold power given according to the policy, then the XG radio can decide to transmit at that frequency channel.
- **Sensing Time Interval/Non-occupancy time / Lookthrough:** The XG radio needs to sense the channel after every particular time period when it is using the channel opportunistically to check the existence of primary user [7].
- **Emission/Transmission Power:** The EIRP (equivalent isotropically radiated power)/ transmission power level of the node can be adjusted according to the policy.
- **On-Time:** This is the continuous transmission time (pulse duration) of the XG device.
- **Off-Time:** It defines the free space/gap between two consecutive transmission pulses.
- **Duty Cycle:** The ratio of the sum of all pulse durations during a specified period of continuous operation to the total specified period of operation. The off-time between the successive packets transmission in the time domain has to be increased to adjust the duty cycle.
- **Emission Power Leakage:** It defines the emissions outside the intended channel.
- **Emission PSD:** "The power spectral density is the total energy output per unit bandwidth from a pulse or sequence of pulses for which the transmit power is at its peak or maximum level, divided by the total duration of the pulses."
- **Bandwidth:** It provides the available frequency band for transmission of data.

5. IEEE 802.11 (WARP2) Tunable Parameters

To integrate XG communication with IEEE 802.11 wireless communication system, the policy parameters discussed above, are needed to map with some 802.11 tunable parameters. Hence, the system can operate according to the policies. In this paper, WARP2 has been considered to define some IEEE 802.11 tunable parameters. The protocol stacks according to the IEEE standard 802.11 are implemented in the WARP2 simulator. However, the Physical (PHY) layer is not fully modeled according to the IEEE 802.11a standard, i.e., the common methods and techniques like the modulation or channel coding methods is not considered in the time of modeling the simulator; rather the packet loss rate (PLR) is directly computed from the carrier to interference ratio (C/I) using a lookup table. The main top level blocks of the WARP2 system structure is given in the Figure 2. Simulation control block is responsible for the initialization, control and the execution of the simulation. Traffic or load generator block generates the packets, whereas the controlling the generation of load is the duty of the traffic generator controller. The IEEE 802.11 block implements the IEEE 802.11 (MAC and PHY) layer mechanisms like random backoff, RTS/CTS method, dataframe fragmentation according to fragmentation threshold, channel sensing etc. The channel block is just to transmit different kind of packets coming from PHY layer of one station to another. It is a simple model of the channel without having complex channel coding techniques implementation.

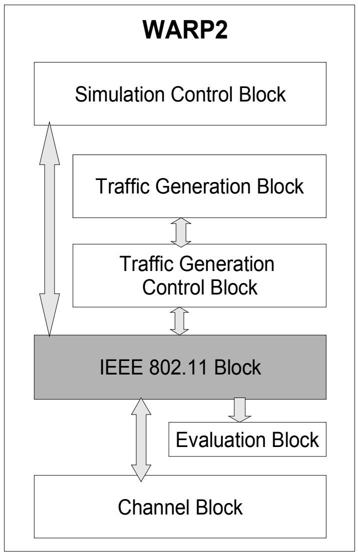

Figure 2: The highest level system structure of WARP2 simulator

In case of an IEEE 802.11 device, tunable transmission parameters would be as follows:

- **Channel Number / Frequency:** Operating channel numbers corresponding to the channel center frequency.
- **Clear Channel Assessment (CCA) Sensitivity Level:** "Clear Channel Assessment is a logical function found within physical layers which determines the current state of use of a wireless medium. Such a function is found in IEEE 802.11 networks and aids in contention avoidance"[5]
- **CCC Inter Sensing Duration:** For sensing the channel periodically, a parameter like the DFSInterMeasurementDuration (time interval between consequence measurement requests in dynamic frequency selection method in WARP2) could be used. It could be CCAInterSensingDuration.
- **Transmit Power:** Transmission power is defined for management, control, and data frames, in mW. At 802.11 these are statically defined by dot11TxPower_Management,

dot11TxPower_Control, dot11TxPower_Data PHY management information base (MIB) parameters and in the case of 802.11h power level can be changed dynamically according to 802.11h implementation in TPC unit.

- **Modulation Scheme / Phy Mode:** In 802.11 the different physical modulation schemes like BPSK, QPSK with different convolution coding rate correspond to different physical data rates in Mbps. These are also denoted as phy mode, for example, 802.11a/g can operate at 6, 9, 12, 18, 24, 36, 48 and 56 Mbps. According to the transmission power or SNR the optimum phy mode can be chosen individually per OFDM subcarrier.
- **Maximum Transmit MSDU Lifetime:** This MIB parameter defines the maximum time duration for how long continuous packet flow can be possible.
- **DIFS Length or Minimum Backoff Interval Length:** By varying this parameter, the gap between transmit packets, hence, the duty cycle of the radio can be controlled.
- **Quiet Period:** If the station needs to sense the channel in which it is transmitting, the station is required to stop its transmission for the predefined quiet period.
- **Number of OFDM Subcarriers (to change the channel bandwidth):** In 802.11 the OFDM signal includes 52 subcarriers inside a 20 MHz RF channel. If the available RF bandwidth is higher or lower, then the no. of subcarriers can be adjusted accordingly.

6. Mapping Parameters between DARPA and IEEE 802.11 (WARP2)

Following shows the mapping between DARPA XG policy parameters and IEEE 802.11 tunable parameters. Inside the parenthesis, the process or block name of the WARP2 simulator is written where the 802.11 tunable parameters have to be adjusted.

For Sensing:

- Frequency (channel number) ↔ Channel Number / Frequency (inside DFS)
- Sensed Power level ↔ CCA sensitivity level (inside CCA)
- Sensing time interval/Lookthrough ↔ CCA Inter Sensing Duration (inside PHY)

For Transmitting:

- Changing channel: Frequency (channel no) ↔ Current Frequency (inside DFS)
- Emission Power ↔ Transmit Power (inside sSetNewPower and sChangeAdhocPower signal in TPC)
- On time
  - If on-time is greater than each packet sending time then nothing to do
  - Otherwise on-time ↔ Maximum Transmit MSDU Lifetime (inside ptMLME_Services)

    On Time should be lower than some threshold duration limit. Packet length should be adjusted according to that. If the packet length is bigger than the threshold, then fragmentation has to be done.
- Off-time ↔ DIFS length or minimum backoff slotCounter (inside ptBackoff)

    DIFS and contention window has to be adjusted to comply with the off time limit according to the policy
- Duty Cycle ↔ DIFS length or minimum backoff slotCounter (inside ptBackoff)
- Emission power leakage ↔ (not implemented WARP2)
- Emission Peak PSD (nW/Hz or dBm/Hz) ↔ maximum power for the channel bandwidth
- Bandwidth ↔ the number of OFDM subcarriers in the channel

    According to the opportunity, the total no. of OFDM subcarriers can be divided over different channels with synchronization symbol (pilot).

7. DARPA XG Enabled Radios

The XG communication technique can be added to a legacy system. However, there should be some interface to incorporate spectrum policies into the functionality of the protocols. And moreover, set of behaviors need to be identified in legacy radio that can be considered for regulatory approval. The XG implementation does not depend upon how a MAC or PHY layer functionality is implemented. However, it may be aware of and exploit specific MAC or PHY layer technologies. XG is mostly a MAC level system; nevertheless, for sensing purpose XG needs PHY layer knowledge also.

An overview of the logical structure of a DARPA XG enabled 802.11 radio is given in Figure 3. It includes following parts. To become aware of available spectrum opportunities, the radio system needs to sense the situational information about the spectral environment at a given location and time. To comply with the dynamic spectrum availability, a **sensor** has to be integrated with the XG enabled radio system. In the case of 802.11, clear channel assessment (CCA) process can be used to sense the channel.

The **radio platform**, which is the primitive radio system, is one of the main parts of the XG enabled system. In fact, the opportunistic use of spectrum will be enabled or implemented over this legacy radio system. As the XG communication system is absolutely limited to the MAC and PHY layer, so an extra block can be added with the legacy radio system horizontally as convergence or tuning block such a way that the legacy one be the subset of the enhanced one. This block can be consisting of the corresponding XG-MAC-TL and XG-PHY-TL which will work as interfaces between the legacy radio and the policy related units; so that set of radio behaviors can be mapped with the policy.

The **Policy Conformance Reasoner** (PCR) gets policy information from different sources like smart media or over the internet. Policies are provided as machine-understandable format in a special

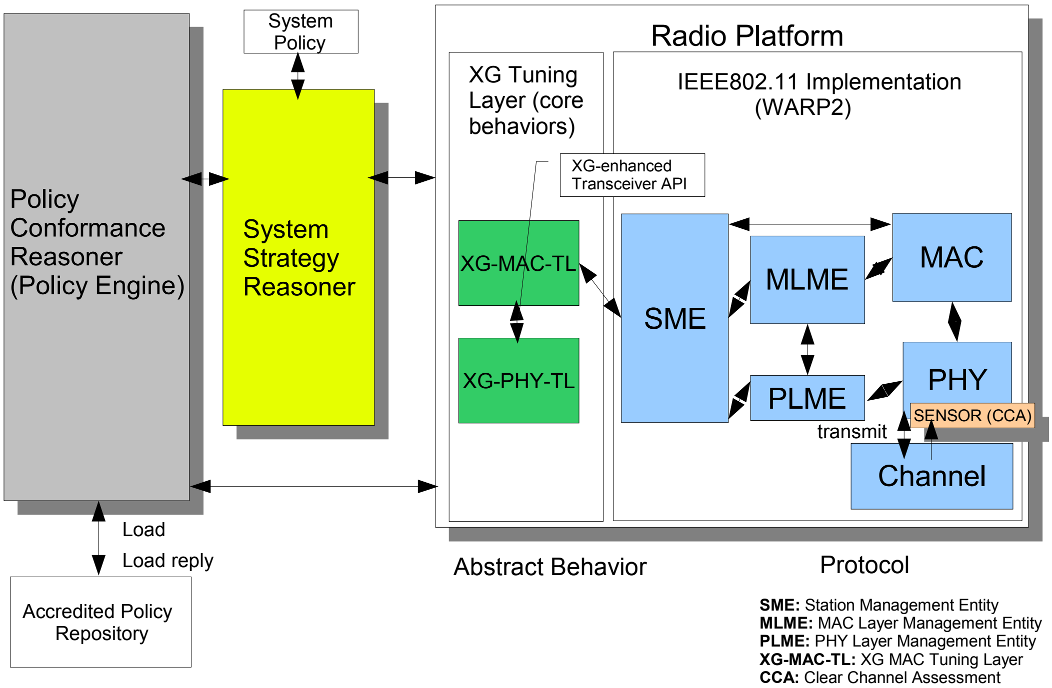

Figure 3: System Model of DARPA XG enabled device

description language called XG policy language (XGPL). The XGPL is based on the ontology language. Due to space constraint of the paper, a detail of XGPL [8] is not included here. After getting the policy information, described by XGPL, the PCR fetches the file, parses it, loads any ontology that it depends upon and converts the policy to an internal processing format so that the policy can be interpretable to the radio and system strategy reasoner. This internal processing format is in such a way that it helps to respond to queries (by a system strategy reasoner) to filter policies based on selection criteria (e.g. to a specified radio, authority or frequency) and to validate the request on the spectrum use proposed by the radio platform. Nevertheless, the PCR software architecture provided in XG Policy Tools version 0.1.1 [9] still has implementation limitation.

System Strategy Reasoner (SSR) determines the opportunistic spectrum sharing strategies for the system according to regulatory and system policy constraints. It queries the PCR for available opportunities in respect to regulatory authority. The SSR particularly deals the system-specific optimization where most of the scope for the state of art lies.

The sequence of operation of these different parts of XG enabled radio could be explained as follows. At first the machine understandable policy rules [8] are loaded in the PCR. Each policy rule is consisting of three parts: a selector description, and opportunity description and a usage description. For example, to encode a statement of policy like "(In Germany) if peak received power is less than −80dBm then maximum EIRP is 10mW", the descriptions can be as follows; selector description: "applies to operation in Germany", opportunity description: "peak received power is less than −80dBm" and usage constraint description: "transmit with maximum EIRP of 10mW". On the other hand, there is instance, a set of bindings that can be validated against description. For example, a valid set of instances for described policy rule can be as follows: selector instance: "operate in Germany", opportunity instance: "received power is −85dBm", usage constraint instance: "transmit at 8mW". When the XG-enabled radio wants to start a transmission, it senses the channel to get the awareness about the situation. This sensing is done in the sensor according to the system strategy from SSR. The SSR can query the PCR to filter the policy constraints. Then based on system and regulatory policy and knowledge of the radio platform, the system strategy reasoner enables the radio platform to find out available spectrum opportunities and a suitable use of those opportunities. The will result in, for example, binding values to relevant parameters. After the identification of opportunities and its usage, they are characterized as selector, opportunity and usage constraint instances and the radio platform forwards this set of instances to the PCR for validation. The radio can use them to transmit if the set of instances is validated against the policies.

8. Implementation of DARPA XG Extensions in the 802.11 Protocol Stack

The basic idea of integrating DARPA XG in to 802.11 is that the existing 802.11 protocol stack should be modified as little as possible. An overview about the signalling between the XG and the 802.11 part is given in Figure 3. The output values of the XG MAC and PHY tuning layer, which means the values to tune the transmission parameters, is sent to the 802.11 Station Management Entity (SME). In the legacy 802.11h protocol stack, the algorithms which decide to change the frequency or the transmit power are located in the SME. Since the XG entity now takes over this task, the decision results taken by the XG entity are fed to the SME. Measurements which the

PHY layer has performed for the purpose of channel sensing are being sent to the XG tuning layer. The tuning layer provides an abstraction between the transmission parameters as they are maintained by the XG model and as they are maintained by 802.11. For example, a frequency given by DARPA XG is translated into a channel number for 802.11.

If the station in concern needs information about the channel quality from another station, the signalling scheme specified in 802.11h is suitable for this task: With a Measurement Request, a station can query an interference measurement from another station and the other station can send back the result to the requesting station by a Measurement Report. In the same way, the link margin of a connection between two stations and the transmitter power of the remote station can be queried by a TPC Request and reported by a TPC Report. Besides the channel sensing, 802.11h also provides means to change transmission parameters: If the frequency needs to be changed, the requesting station can send an 802.11h Channel Switch Announce. This signalling framework can be extended to request the sensing of parameters as specified in 802.11k. Besides the interference and link margin sensing, 802.11k defines for example the sensing of the channel load or which neighboring stations it can see in its environment. 802.11k does not specify the control of transmission parameters which means the only way to do so is the Channel Switch Announcement defined in the 802.11h standard. However, for the remote control of other parameters such as the transmitter power or the number of OFDM subcarriers to be used, it is easy to extend the structure of the 802.11h Channel Switch Announcement management frame accordingly.

If signalling on the radio channel is needed to request measurements or the change of a transmission parameter from a remote station, the SME sends this request to the MAC Layer Management Entity which generates the appropriate management packets. These packets are then sent to the MAC and PHY layer for transmission. The generation of management packets to query the sensing of various channel parameters is specified in 802.11h and .11k. For the generation of management which requests the turning of transmission parameters of a remote station, the Channel Switch Announce frame of 802.11h can be modified accordingly to request changes other than the frequency [10, 11].

The only modifications are some signalling of the transmission parameters from the XG unit to the 802.11 stacks and information about the channel which is sent from the 802.11 PMD block to the XG module. The 802.11 block is integrated as the radio interface like it is shown in Figure 3. This figure denotes to which units of the protocol stack the external signalling is applied. In 802.11h, decisions when to change the frequency or the power, or the decision to take a measurement, are taken by the Station Management Entity (SME). In the MLME, the appropriate signalling is performed to inform the communication partners about required measurements or transmission parameter adjustments. This 802.11h signalling framework can be used to create a DARPA XG enabled device: the signalling to take measurements can support the channel sensing in the way that a station can request measurements from other stations as well as take own measurements. If the communication partner should select another transmission opportunity (frequency, power), then also the 802.11h framework can be used with some extensions. The 802.11 specification defines spectrum management frame types for the interference measurements on different frequency channels, to determine the link margin on a certain link with a communication partner, to adjust the frequency and transmit power and to quiet the channel. This signalling framework can be extended to request adjustments of other parameters such as the number of subcarriers or the DIFS length to be used.

9. Example of Policies and Respective Mapping in XG Enabled Radios

The Federal Communications Commission (FCC) has recently proposed allowing unlicensed use of vacant TV bands. This willingness of the FCC in recent years to open up spectrum for unlicensed commercial use, will likely continue and eventually break the spectrum scarcity bottleneck. In this section, an artificial example of radio policy for the signals in all TV bands is considered which has no connection with FCC and it is a mixture of examples given in [8, 12]. Secondary level policies, as following, can be given for the XG radio that is capable of operating in TV bands.

- **Geo-location:** The use of XG radios in these bands is limited only in areas governed by USA spectrum policies
- **Time:** This policy expires at 00:00 hrs GMT on December 1, 2007
- **Sense Power:** The XG Radio may transmit on channels where the received spectral power in the channel is less than −90 dBm
- **On-time/Off-time:** The continuous on-time of the XG radio must not exceed 5 milliseconds (ms), the off-time must not be less than 4 ms
- **Duty cycle:** must not exceed 50% across a 2 second period
- **The maximum emission power:** shall be less than 20mW
- **Sampling Time Duration:** The XG radio sensor must sample at least once every 6 seconds.

The example policies just described before are mapped to DARPA XG enabled 802.11 radio. The region, authority and time descriptions are the part of selector description in the machine- understandable policy file. Generally in 802.11, a valid OFDM transmission at a receive level equal to or greater than the minimum 6 Mbit/s sensitivity (−82 dBm) shall cause CCA to indicate busy. In the XG enabled 802.11 radio, the sensitivity level is adjusted to −90 dBm to check whether the intended channel is busy or idle. Due to the limited packet length (2312 bytes) for legacy 802.11, the continuous time for transmission (3.108 ms) is lower than the specified 5 ms. To adjust the off-time between two consecutive packet transmissions according to the policy, the DIFS length is set to 4 ms which matches both the off-time and the duty cycle (less than 50%) criteria. The transmission power is adjusted in such a way that it should not exceed the power level given by the policy. In XG enabled 802.11 radios, channel sensing interval could be adjusted by CCAInterSensingDuration.

10. Conclusion

One of the visions of the DARPA XG program is having a framework for flexible radio regulation where the radio devices can reconfigure their way of operation to adapt to the evolving/new FCC regulatory environment. The approach discussed in this paper to IEEE 802.11 radio system in such way that it can control the multidimensional system behaviors by the authorized policies. Different XG policy parameters and IEEE 802.11 tunable parameters have been investigated and mapping strategy among them has also been determined. A structural model of the 802.11 radio system has been extended for supporting XG communication with extra modules like PCR, SSR. The extended system could adaptively access spectrum opportunities and hence the overall spectral efficiency of the system could be increased.

REFERENCES

[1] XG Working Group, *"The XG Vision"*, Request for Comments, Version 2.0, Prepared by: BBN Technologies, Cambridge, Massachusetts, USA, January, 2004

[2] XG Working Group, *"The XG Architectural Framework"*, Request for Comments, Version 1.0, Prepared by: BBN Technologies, Cambridge, Massachusetts, USA

[3] *"Wireless Access Radio Protocol 2"*, http://www.comnets.uni-bremen.de/~mms/warp2.html, September 22, 2005

[4] *"This is WARP2"*, http://www.warp2.de

[5] IEEE Standard 802.11-1999: *"Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications"*

[6] IEEE Standard 802.11h-2003: *"Spectrum and Transmit Power Management Extensions in the 5 GHz Band in Europe"*

[7] William D. Horne, *"Adaptive Spectrum Access: Using The Full Spectrum Space"*, The MITRE Corporation McLean, VA, 2003, www.tprc.org/papers/2003/225/Adaptive_Spectrum_Horne.pdf

[8] XG Working Group, *"XG Policy Language Framework"*, Request for Comments, Version 1.0, Prepared by: BBN Technologies, Cambridge, Massachusetts, USA, April, 2004

[9] *"PCR Software Architecture"*, http://www.ir.bbn.com/projects/xmac/pollang.html, XG Policy Tools version0.1.1

[10] A. Könsgen, C. Görg, *"Performance Evaluation of Dynamic Frequency Selection Strategies, IEEE 802.11h Based Networks"*, Proc. 1st Regional Conference on ICT and E-Paradigms. Colombo, Sri Lanka, 2004

[11] A. Könsgen, A. S. M. Hossain, C. Görg, *"Transmit Power Control Algorithms in IEEE 802.11h Based Networks"*, Proc. 16th Annual IEEE International Symposium on Personal Indoor and Mobile Radio Communications. Berlin, Germany, 2005

[12] *"News Release: FCC Reallocates television Channels 60–69 (786–806 MHz) to Other Services"*, http://www.fcc.gov/Bureaus/Engineering_Technology/News_Releases/1998/nret8001.html