

AN INTERFERENCE TEMPERATURE MODEL FOR IMPROVING SPECTRUM ACCESS

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Abstract

In an effort to improve radio spectrum management and promote more efficient use of the spectrum, the Federal Communications Commission (FCC) is trying to adopt a new model to quantify interference. The objective of my research project is to develop an "Interference Temperature" (IT) model for this purpose. The IT model aims to create a reference interference level using real-time measurements and predictions based on the actual RF environment seen at a receiver. This resulting interference temperature would reflect the total amount of RF energy present at the receiver within the operating band at any given point in time. The transmitter would configure itself in response to this value. This paper reviews some of the technical challenges involved in the implementation of such a model. It discusses several proposed approaches. The advantages, disadvantages and some possible applications for this metric will be investigated and analyzed. As an example, I discuss how the IT concept could be used in a proposed plan for frequency sharing plan between existing TV broadcast stations and new unlicensed services using Software Defined Cognitive Radios.

Interference Temperature Model

Interference Temperature Definition

In an effort to improve radio spectrum management and promote a more efficient use of it, the Federal Communications Commission (FCC) is attempting to adopt a new model to measure interference within the bands that they regulate. This emerged as part of a new set of initiatives introduced after a set of hearings during the late 1990's in which industry and academia were able to participate¹. The impact and possible importance of these initiatives for the future of RF communications have been felt throughout the United States as other agencies responsible for spectrum management such as the National Telecommunications and Information Administration (NTIA) and the Department of State are trying to take a similar approach. Also, this impact extends beyond our geographical border as other countries all over the world are looking to adopt similar initiatives².

The interference temperature model aims to use real-time measurements and predictions based on the

actual RF environment seen at the receiver end and uses it to adapt their behavior/operation dynamically to these measurements. This resulting interference temperature would reflect the total amount of RF energy present at the receiver end within the operating band at any given point in time. More specifically, at this time the Commission proposes to formally define interference temperature as "a measure of the RF power generated by undesired emitters plus noise sources that are present in a receiver system (I + N) per unit of bandwidth,"³ or, in other words, the temperature equivalent of such RF power measured in units of "Kelvin" (K). In addition to the interference source described above, the proposed interference temperature metric could include out-of-band or unwanted emissions from both co-channel and adjacent channel transmitters. Interference could be defined as the cumulative effect of all undesired RF energy present in a specific frequency of interest. "Interference will occur at any given receiver at any given point in time when the cumulative level of undesired signals plus noise at the receiver exceeds its tolerance threshold"⁴.

The model currently used by the Commission for regulating spectrum and limiting interference focuses only on the transmitter's overall performance and imposes the regulations on its operation in the form of a transmit output power "mask". This approach is static and based on theoretical assumptions of how much interference is created by transmitters under a variety of operating parameters or conditions and not on actual measurements. The set of parameters used for these calculations are, for the most part, a reflection of the worst case operational scenario in which the device is operating at maximum power and occupied bandwidth. This creates a large margin for error as the probability that all the active devices are operating under these conditions at the same time is very low. In addition, advances in radio technology have provided the industry with 1) the development of transceivers with much less noise contribution per emitted power, and 2) for the devices to collectively operate under more efficient conditions allowing for the current communication systems to operate at much lower interference levels and to be much more tolerant to such interference as well.

This new model would help create a new standard for quantifying such harmful interference and it would provide the current band users or licensees with a more accurate interference measurement that could then be used to improve spectrum utilization. As stated by

several parties during the comments⁵, the absence of such a standard has proven to be a deterrent to the introduction of new and promising technologies such as UWB, LPFM and others. The interference temperature could help improve spectrum usage by setting a maximum permissible interference level more accurately within a band. This level could vary within geographical areas. This could allow a larger number of users to operate at the same time with greater certainty of their overall effect in the occupied spectrum. Also, being a more accurate measurement, it would provide greater protection against harmful or disruptive interference that could be generated at any given point in time. In the event that the IT level or “cap” is not yet reached, there could be the opportunity for other devices to operate. As seen by the Commission, spectrum efficiency is determined by the number of users per unit of bandwidth. This could potentially increase both the licensee’s, as well as, the public’s benefit derived from the use of the spectrum as it could open the doors for the establishment of secondary markets.

One of the largest challenges that the implementation of an IT model faces is the accuracy in which interference could be measured. This could be more evident in the cellular bands as mobility is a big factor. As the number of mobile devices and the user’s demand for spectrum increases in any specific system, the more difficult it becomes to detect and identify its RF footprint and contribution to the overall interference. This issue becomes more critical if the devices were granted access to a broader spectrum.

Proposed Implementations of the Interference Temperature Model

Based on the SPTF recommendations⁶, the Commission proposed three different ways in which they believe the implementation of the IT model could be accomplished.

The first approach suggests that the entire process should take place within each individual device. The device will be responsible for measuring the RF environment, calculating the corresponding interference temperature at its location, and make the decision of a transmit/not transmit based on the calculated IT level taking into account its own contribution of RF energy. It is evident that the amount of computational power and complexity required on a device to perform such a task without compromising its communication’s performance exceeds the current device capabilities available (offered) at this time.

The second approach will require the implementation of individual receiver sites dedicated to measure the RF environment and calculating the corresponding interference temperature level. This information will be transmitted to a central site location where the interference temperature profile would be calculated for the specific geographical market. It will then be up to the central site to communicate the transmit/not transmit instruction to each device in the field. The degree of complexity that this approach imposes for its implementation will be discussed later on in this work.

As a consideration to current licensees and as an opportunity for the establishment of secondary markets, the FCC proposes a third approach. In the bands that are currently licensed, the providers could establish a grid of monitoring sites similar to the ones proposed in the previous approach. These sites would continuously examine the RF energy levels in their specific band or bands and process the data to derive the corresponding interference temperature level. This IT level will then be made available by way of a broadcast to subject transmitters with interest in utilizing the specific band. This specific broadcast could be on a dedicated frequency similar to a pilot signal used in today’s cellular networks with instructions on how those secondary market transmitters should respond.

Proposed Spectrum Management Models

To have a better understanding of how the three IT model approaches mentioned in the previous section could be implemented, we will have to consider the ways in which the Commission is considering to regulate the RF spectrum and its interactions as part of our overall analysis. As part of the same study, the SPTF described three different models for assigning spectrum usage rights. These methods are the command-and-control, exclusive use or property-rights, and the commons models. Both the SPTF report and an article by Faulhaber and Farber (2003), provide a more detailed discussion of these three methods.

The command-and-control method is the one currently implemented by the FCC for spectrum management. The intention of this model is to provide the highest level of protection to each one of the authorized users. Traditionally this has been achieved by imposing very tight regulations on the amount of emissions that each device could generate (i.e. the amount of interference to others). This includes both the co-channel and adjacent channel emissions. If an IT model were to be implemented under this spectrum allocation regime, it would have to be the second IT model discussed above. The Commission would have control of the monitoring grid as well as the establishment of the corresponding

interference levels. This model is more likely to be used on bands in which it is imperative that the incumbent services are not to be disrupted such as emergency and public safety bands, GPS, military and others. It is important to mention that the Commission has made it clear that it is trying to move away from this type of spectrum management practice. This will incline us to believe that the Commission has no true plan (intentions) to pay, support and even to subsidize the deployment of such a system.

The third IT model looks to be a perfect application under the property-rights regime. Here, a well-defined set of rules guiding interference could be put into place to guarantee that the incumbent service does not get affected. Even though there are already strict guidelines in place to reduce interference, these are based on the static interference management approach discussed earlier. Although this set of guidelines could be used as a reference point, a new set will need to be developed to be more dynamic to conform to the IT model concept. This would be considered as an extension of the services where the incumbent could have total control of how much interference he is willing to tolerate without being a detriment to its primary service. As long as a mechanism to broadcast and share this information can be put into place, it would be possible for a network or networks of underlay devices, such as 802.xx devices, to operate until reaching the preset interference level. Such a concept can be incorporated as part of the device specifications and standards that the FCC governs and oversees. The FCC will take a “hands-off” approach to managing the spectrum while making certain that the main priority is to protect incumbent services. This gives the incumbents the opportunity to enhance their services and revenues while improving spectrum efficiency.

Under the commons regime the main objective is for all the devices to derive the maximum benefit of the occupied spectrum. The levels of interference could be set to be totally dynamic and will depend on the devices interactions and spectrum usage. It would be common sense for the devices operating under this regime to avoid and/or minimize interference to obtain the best quality of service. This concept opens the opportunity to exploit the capabilities of new emerging technologies such as software defined (SDR) and cognitive radios (CR). With the ability to dynamically adjust internal parameters such as transmit power, coding, and frequency of operation; these radios should eventually drive the level of interference to an equilibrium level where optimally

it will reach a minimum for all the active devices. The combination of the commons regime, the IT metric and agile radio technologies has made the Commission’s idea of the “hands-off” approach for managing the spectrum so attractive to the point that the Commission has issued a Notice of Inquiry (NOI) and Notice for Proposed Rule Making (NPRM) to investigate further the feasibility of this idea.

In addition to the different proposed IT implementations and the spectrum management models, there is a need to look at each specific RF band that the model could be considered to be implemented on. Each band is licensed by the FCC for a particular service which subsequently determines the specific technology that is to be used for the wireless communication. Both, the technology used, as well as, the physical location of the functional receivers that will be affected by the presence of interference are critical as they will determine its sensitivity and ability to reject such interference. The effects of applying the IT model to spectrum that is allocated for services where receivers are fixed would be totally different than when applied to spectrum that is allocated for services where receivers are portable or mobile (such as cellular services). A similar situation occurs when the receivers are far from the source of interference such as in the Satellite uplink bands or are at fixed locations that need not be registered with the Commission.

As wireless communications move more and more towards digital services, the interference management issue has become more important. Cellular service is a prime example of how system capacity is limited in great part by interference, more specifically self-induced interference, and of what is being done to overcome this problem. The proliferation of such cellular services has continued to promote improvements in the techniques used for the transmission of the data (CDMA, TDMA, etc.) as well as the device performance per se. Better schemes for coding, spreading, and power control have been implemented to minimize the required transmit power thereby minimizing the overall RF level present in the band allowing for greater capacity. As noted by Cingular, as a result of these improvements, the interference level resulting from signals of undesired mobile units has decreased dramatically, causing a reduction in the overall noise plus interference floor at base station receive sites. In addition, the system noise floor has also been reduced by improvements in base station receiver performance, with the noise figure dropping from about 8 dB to about 4 dB, permitting a further reduction of about 4 dB in the received noise floor.⁷ While these techniques work to increase capacity, their improvements are still limited by the available statically allocated spectrum and their inherent behavior. In addition, these techniques do not take into

consideration the radio environment, which is dynamic and can dramatically change in time, space, and frequency, especially for such mobile radios. The effectiveness of these techniques could be greatly improved by allowing the radio to take some additional actions regarding its operational parameters. These changes can take place in one or more of the layers of the communication protocol stack (physical, MAC, network, transport, and application layer) and they can be used to satisfy the network's and/or the user's needs, regarding bandwidth, power, data rate, etc. However, even though all these improvements had help in dealing with interference and capacity they do not aid in the control of interference generated by other technology sources that can be introduced into their system.

In addition, the development of cellular devices has shown consistent receiver technology improvements. Direct Conversion Receiver (DCR) is one of the new emerging front-end configurations that reduces the number of components needed in the RF link thereby providing a reduction in overall noise. Also, both cryogenically and Peltier (or thermoelectric) cooled technologies are being developed and implemented to create low-noise ultra-sensitive receiver front ends. These technologies provide increased sensitivity at the receiver end and, as a result, the devices require lower system signal levels to operate. This will allow a reduction in output power requirements for the entire system. Another new and promising development is in the area of superconducting microelectronics technology. Hypres, Inc. is one of the leading companies in this area of research and has provided the industry with some promising resultsⁱ. With promises of extremely high sensitivity, ultra-low power, and inexpensive IC fabrication, just to mention a few, it makes this technology the perfect candidate for the development of new front ends. The ideal scenario will be one in which all the internal thermal noise in the receiver chain is minimized and the system noise is dominated by the antenna noise (and/or interference) temperature.

These innovative technologies are in the early stages of development and most of them suffer from a high cost precluding them from being widely deployed. Also, unless all users use the low noise technology to lower their power level requirements simultaneously and hence permitting the entire system to operate at lower power levels, these innovations become useless. Last, but not least important, this increased sensitivity also results in increased susceptibility.

ⁱ Hypres, Inc. website.

The susceptibility effect, even though not present in a link budget calculation, will result in system performance degradation.

It is evident that advances in radio technology are allowing for a better and a more efficient use of the spectrum as well as influencing the way that the Commission is considering regulating it. With the expected introduction of devices able to perform these tasks in the near future, this has pushed the FCC to further evaluate the urgency in which these changes are needed.

General and Technical issues

There are many general and technical issues that the three possible implementations of IT could face. The general issues are composed of the benefits and drawbacks that the IT model has to offer without considering the technical requirements that such an implementation will impose. The benefits of the IT metric can be seen in many different aspects of its implementation. The establishment of the IT metric will provide a standard for measuring harmful interference in an existing environment. The absence of such a standard has proven to be a handicap for the Commission when trying to impose sanctions. The lack of clarity regarding interference issues has been the base for lengthy and difficult on-going disputes in front of the FCC throughout the years. The establishment of such a standard will help in identifying violators and expedite the resolution of such disputes. In addition, this lack of clarity has been a detriment to the introduction of new and promising technologies such as Low-power FM (LPFM), Ultra-wideband (UWB) and others throughout the existence of the Commission. Even though after the amendments in 1983 in which the Commission adopted the idea "to encourage the provision of new technologies and services to the public",ⁱⁱ it could have been expected that such an introduction would be easier than what is has been. This is based on the Commission's view that "anyone who opposes a new technology or service will have the burden of demonstrating that the proposal is inconsistent with the public interest". Once again, because of the lack of a well-defined standard, the outcome of these efforts has proven to be the opposite.

Another benefit could be seen with little or no modification to the existing spectrum management scheme. Current licensees could benefit from the ability to measure their own interference levels and their technology's tolerance to it. This would provide an

ⁱⁱ 47 U.S.C. § 157.

additional tool to help improve their current system capacity.

A set of drawbacks can be found as we analyze what would it take to implement the IT metric. Spectrum measurements, overall planning, acceptance or approval, and budget are only a few aspects that impose some of the most difficult constraints. Even though, a lot of efforts are currently devoted to studying the existing spectrum utilization, this task has proven to be more complex and time consuming than originally expected. The measurements of frequency and respective power are needed to be taken not only on the spatial regime (geographical) but also in the temporal (time) regime. Just to offer an idea on how far this has pushed the Commission, the temporal effect is something that the Commission's current policies do not take into account. The ability to obtain accurate measurements, which could be crucial for its acceptance, has added to the total time that it would take to study and understand the spectrum. In addition, the need to decide on what to measure and how to measure it will play an important part as well. A more detailed description of this subject will be analyzed later in the technical section. Overall, the time that it may take the Commission to study the current spectrum could prove to be the largest obstacle to overcome. To help in this endeavor, the Commission has opened themselves to comments through several proceedings (Technical sections, NOIs and NPRMs). Meanwhile, the planning on how to implement the IT metric is under way. The issues of required infrastructure, device technology, and investment are being looked at in detail. With the idea of imposing these kinds of changes, the Commission is concerned that it will be responsible to carry the burden of providing the financial backing for the required infrastructure. Last, but not least important, is the analysis on how to transition the already existing and complex spectrum management plan to the new approach.

Based on the comments already filed during the above-mentioned proceedings, the Commission faces a strong opposition by the current licensees. Concerns about who gets to set and control the IT levels sits on the top of their own personal agendas. Questions such as "Could IT provide a feasible means of protecting all licensees from harmful interference caused by "forced" underlay devices?" and "Would there be a derived benefit, either monetary or by getting access to the additional spectrum, to them by the IT implementation?", are weighing heavily against the IT metric acceptance.

Technology and the IT implementation

The need to measure and identify interference in the environment has become an issue of great importance as the demand for the spectrum continues to increase and the performance of the wireless devices are already stretching the limits of current technology. More efforts need to focus on what to measure and how to measure it. Interference can be measured in many different ways. Noise Temperature, Power Spectral Density (PSD), Flux Density, and Signal-to-Noise (SNR), just to mention a few, have already been used to characterize the RF environment. These measurements reflect either the overall RF energy or the ratio of this overall RF energy with respect to the signal of interest. The sets of measurements mentioned previously are currently being proposed to be used as an alternative to the interference temperature approach. Interference Temperature, as a measurement, is only another way to look at the RF energy content. One of the biggest technological weaknesses of the IT model as proposed is that it does not provide any specifics in terms of what it really intends to measure. The controversy between if it intends to measure either the total RF energy or the amount of interference to a given signal has diminished the importance of the possible contributions that this model has to offer. As proposed, it is only clear that it will provide the corresponding temperature for an existing RF level in any corresponding band or channel. Unfortunately, it does not provide any information regarding spectrum availability which could be the essential key to the success of its acceptance and implementation. Even though, this IT concept has its roots in the Satellite bands, where a similar well-established method is successfully used to measure the signal strength, the rest of the wireless world questions its usefulness and need. The proposed implementation should be looked at beyond the actual measurement as it extends into the establishment of a reference level to the RF environment.

As noted by Hypress, Inc.⁸, there is the need to incorporate several steps to reach a useful IT implementation. I recognize the need for at least two of these factors which includes baseline spectrum measurements and continuous monitoring. Baseline spectrum measurement, which refers to the initial spectrum characterization, is crucial for the understanding of current spectrum utilization. With the data collected, an exact representation of the RF environment can be created and an accurate IT model can be set to reflect this with respect to the current wireless technology being used. As mentioned earlier, the Commission has seen the importance of this step and has already started collecting information regarding the spectrum usage in several metropolitan markets. After the initial characterization,

continuous measurement and monitoring are needed to identify abnormalities, identify violators, determine new spectrum usage, etc.

It is obvious that the IT implementation does require for the devices to be aware of their environment to be able to determine the current level of interference. In addition, the device will need to have the capabilities to estimate its own interference contribution given the user's requirements (QoS, bandwidth, security, etc.). The resulting difference between the measured interference level and the preset IT cap will determine spectrum availability. The ability for any given device to act upon the evaluation of this information is the factor that will determine the usefulness of the implementation. The awareness could be obtained in one of two ways, direct sensing by the individual device or as indirect information provided to the device by a monitoring/external system.

All of this, in addition to the possibility that the new wireless devices may have the opportunity to search the entire spectrum to find a suitable frequency for its operation, has expanded the horizons in which radio technology is looked at. The required device functionality to accomplish this task does point to new technologies such as Adaptive-aware and Cognitive Radio (CR) as enablers for the IT implementation and dynamic spectrum management.

A radio that can incorporate information regarding the current spectrum usage and channel conditions could specifically adapt itself to alleviate spectrum cluttering and provide a better quality of service (QoS). More generally, an *adaptive-aware radio* is an adaptable radio that can sense and/or receive information (e.g. spectrum occupancy, interference level, propagation effects, location, policy constraints. etc.) about its environment to help direct the adaptation. However, adaptive-aware radios are unable to react to situations outside of their pre-determined behavior to better manage their own radio resources in new and unexpected situations. To take greater advantage of wireless techniques and available information, developers keep increasing the access to the number of adaptable radio parameters.

Also, as these radios try to take greater advantage of wireless techniques and available information, they must deal with more complex management and analysis problems due to the number of adaptable radio parameters continuously increasing. An added layer of intelligence could give an adaptive-aware radio the capability to better satisfy the users and the network needs. This level of intelligence could

include, but is not limited to, learning, the ability to interpret data, and the ability to create a solution. A *cognitive radio* is an aware-adaptive radio that can learn and interpret knowledge (previous situations, actions taken, and outcomes) to direct the radio's adaptation. Learning is the process of acquiring data to direct and improve future decisions and actions. The data will consist of previous situations, actions taken, and their consequences. Learning continuously improves the cognitive radio's ability to adapt by building up its knowledge as new actions are taken and situations are encountered. Because of its ability to learn, it can better alter its parameters and adapt to continuously changing environments.

The cognitive radio's capabilities could also be extended by allowing radios to share its acquired knowledge. This helps improve other radios' performance by giving them the tools to analyze the situations they have never come across but others have. Even with the range of possible adaptations, a cognitive radio will be constrained to obey any given rules provided by any regulatory body.

The realization of CR is still in the development stages but not far from reality as it leverages on existing software defined radios (SDR) as its enabler. SDRs offer a flexible reconfigurable platform needed for CR implementation but currently deals with issues of flexibility, speed, power consumption, size, price, just to mention a few, making its availability difficult. Interest in cognitive radio research has been expressed at universities like Rutgers, Berkley, and VT and government and military bodies such as DARPA and the FCC. Additionally, the IEEE has formed a working group around the concept of cognitive radio called 802.22.

Research Direction

CWT current research focuses on the development of a distributed cognitive engine that will enable any radio with adaptable parameters to become truly cognitive. The cognitive engine is totally hardware independent and it is currently running on a PC based computer acting as the radio interface. Figure 1 shows a more detailed view of the cognitive engine approach.

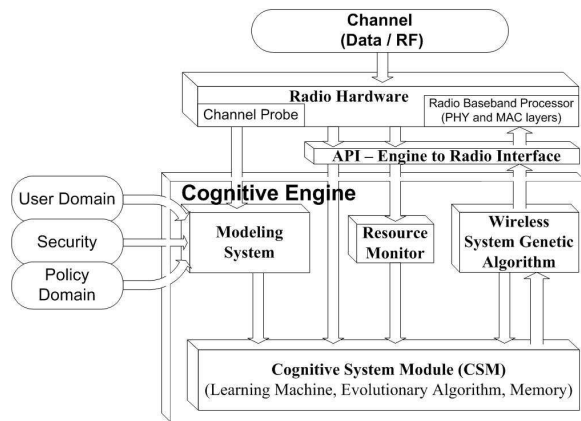


Figure 1. CWT's cognitive engine

My initial research work will focus on helping to further develop the VT-CWT cognitive engine. We are currently involved in the investigation of the regulatory aspects of spectrum efficiency reform and the possible implications that the implementation of cognitive radios could have on the reform. Subsequently, we would like to make a contribution to the FCC proceedings by providing an analysis of the effects of the implementation of CR along with the IT model on spectrum management. A cognitive radio (CR) network testbed is proposed in which the IT metric concept can be investigated and implemented as a means to improve spectrum access and efficiency. This CR testbed will be implemented under the first IT model described at the beginning of this document. Two important parts of the proposed experiment are the characterization of the TV band spectrum and the quantification of the participation effect of cognitive radio in improving spectrum efficiency.

Proposed Experiment

In order for CWT to quantify improvements given by the incorporation of cognitive radio networks as part of the spectrum management efforts by the FCC, a set of experiments are being proposed. Before we can quantify any improvement in spectrum use, we will need to analyze its current utilization. It would be an enormous task to try to characterize the entire spectrum; therefore, a decision to define a limited spectrum of interest to constrain our analysis has been made. Four different bands are being considered to conduct our preliminary experiments. These bands are the TV, FM, ISM, and the Amateur radio bands. Given the limitations of equipment, time required for measurements, and complexity involved in quantifying the spectrum only one of these bands will be investigated at this time. The TV band has been selected because of its well-defined

characteristics and the FCC's recent considerations to reform this band to allow radio users to fill in the gaps left by unallocated TV channels in a given geographical area.

The initial experiment will be conducted in two different scenarios. The first is intended to be used as a controlled experimental environment used to characterize the effect of any given interferer to the TV signal and the TV receiver in use. Here, a standard NTSC TV signal will be injected into a TV set through an RF modulator while an interferer is added to corrupt the original signal integrity. The experimental setup is shown in Figure 2.

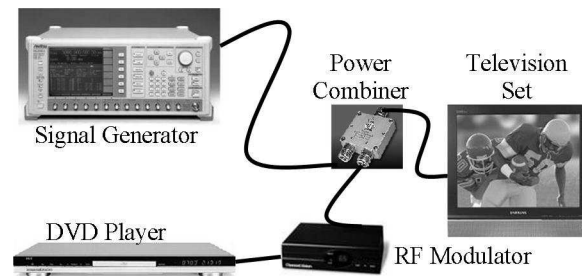


Figure 2. Control experiment setup

The original signal could be originated using a standard video reproduction unit such as a DVD player. Two different signal sources can be used to quantify signal quality, a test pattern and a regular video movie, where the signal level could be set with great accuracy. The signal then will be fed to an RF modulator which will allow us to select any given channel within the TV band of interest. The RF signal will then be fed to a T-combiner where the interferer is to be added. Here, a signal generator will be used as the source of interference given the flexibility that it offers on the creation of different signals.

For simplicity and practical considerations, the cognitive radio network will be emulated as a wireless service using Direct Sequence Spread Spectrum (DSSP) similar to the WLAN networks in use today. This will allow us to use White Gaussian Noise as the interferer source. The interferer power level will be adjusted until noticeable signal degradation, either video or audio, is observed at the TV set. Because of the FM modulation's inherent capability to withstand noise, we expect the video degradation to occur first. At this point we will consider that a maximum level of interference has been reached. This experiment is then to be repeated in all the different channels and an average interference level will be calculated. This will provide us with the maximum tolerable interference level for the given TV channel. The interference temperature level cap could be set a few dBs

lower than this average to allow for a safety margin. This set of measurements will provide a more detailed view of both the effects of co-channel and adjacent channel interference. This also provides a measure of any inter-modulation product that could occur given the inherent nature of the TV receiver's design when an adjacent channel is occupied.

The second scenario will be for the spectrum occupancy and over-the air signal measurement phase in which a setup similar to the one shown in Figure 3 will be used. This basic setup will require the development of an antenna with good characteristic performance to cover the TV bands.

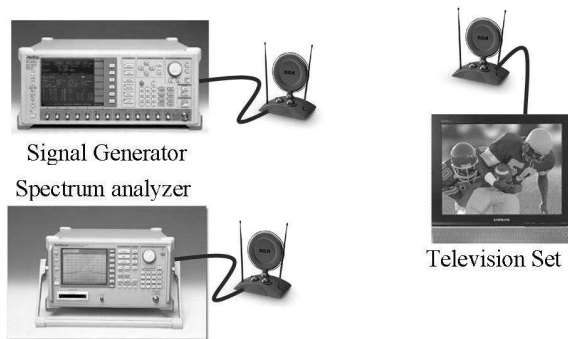


Figure 3. Over-the-air setup

The spectrum analyzer required to perform the measurements will need to have good noise floor level characteristics (below -135dBm) and good dynamic range to differentiate between the strong TV signals and the weak signals generated by the wireless network to be implemented later. A computer will be used as the data collection point and also to calculate and display the final spectrum density characteristics. After the spectrum is characterized, an experiment similar to the one detailed in the first scenario will be performed with the exception that both the RF NTSC signal as well as the interferer will be broadcast over the air.

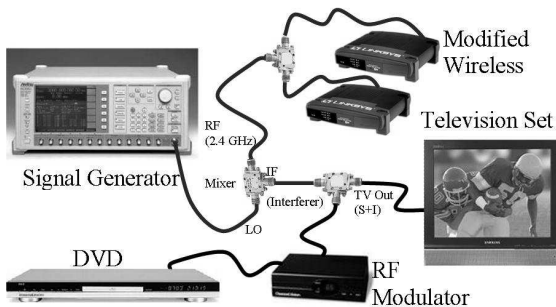


Figure 4. Network emulation setup

The final part of the experiment shown in Figure 4 would then include the incorporation of two modified wireless access points as network traffic emulation. These access points are to be controlled by computers running CWT's cognitive engine. The cognitive engine will receive information regarding interference level, the IT cap, user or application needs, etc. and it is expected to make the decision to transmit/no transmit given those conditions. The cognitive engine will also have access to a very limited set of radio parameters such as transmit power level and transmission rate. This work can then be extended to include multiple access points to more accurately reflect a complex wireless network environment. This set of experiments will evaluate the cognitive engine performance and decision making capabilities given a certain interference level, an IT cap, and the estimation of its own interference contribution given the application's requirements.

Conclusions

This paper presented an "Interference Temperature" (IT) model overview of how IT could measure and quantify wireless system interference as proposed by the FCC. It also reviewed some of the technical challenges as well as the complexity involved in the implementation of such a model. Several proposed approaches were discussed. The advantages, disadvantages and some possible applications for this metric were investigated and analyzed. Subsequently, a model for implementing the IT concept in the proposed frequency sharing plan between the existing TV broadcast band users and new unlicensed services using Software Defined Cognitive Radio was presented.

The implications of the implementation of a new model such as the Interference Temperature metric would transcend the technological arena. Besides the technical aspects, spectrum allocation involves social, economic, and political issues as well. In addition, the possibility of allowing unlicensed devices (underlay devices) to access current licensed spectrum could result in the proliferation of new services in the wireless market.

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