

INTERCONNECT COMMUNICATIONS

A Telcordia Technologies Company

Risk as an Alternative to Price in Determining Access Spectrum Rights

Concepts for a New Approach



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In capitalist economies we are well accustomed to using price to determine who gets what resources. In the background, though, we continually have that nagging doubt that price is not always the fairest way; an influence perhaps from our beliefs in social justice. This spawns the ideas that resource should be apportioned first to those with the greatest need. But the all-time difficulties with this are election of the decision maker and determination of what 'best use' metric might he employ by which to decide who gets what.

This brief paper looks at a simple concept for making spectrum assignments and allotments. It posits that in the public domain with military and police services and other governmental agencies, there is a final arbiter – the commander. Whilst we don't expect the commander himself to make the assignment or allotment, his proxy, the mission spectrum manager, will in his stead. Given this, on what basis should he make the decision? In the past the ideas of de-confliction and minimisation of harmful interference have prevailed. Rudimentary tools have been applied to keep users apart whatever their contribution to the mission. As spectrum becomes more congested and users in one country may expect interference both within-country from own-service-users and others and from across borders, we perhaps need to accept that, in the future, harmful interference is inevitable – the only issue is the degree. Harmful interference denies users service. Service denial at the hands of others might be classed as an untoward spectrum management event – hopefully occurring infrequently in time and locations leading finally to a probability of successful spectrum use.

This paper examines how this probability of successful spectrum use might be developed from the existing body of knowledge. It develops the concept of 'commander's intent' as a proxy for mission importance and it shows how spectrum assignment and allotment may be made using the two in a simple expression.

Enter the Players

To reach conclusion and evaluate the method, we need to first understand the environment. This is easily done using a use case model effectively analysing who, in a particular region on Earth, makes use of the spectrum. Figure 1 (overleaf) shows this at the highest level.

The primary player and the subject of our discussion is Our User. He will make use of some assignment or allotment¹ running some service to the benefit of his stakeholders. With this user though with differing individual objectives but perhaps a

¹ An allotment here is a block of spectrum defined and for use over space and time. In it, a user may do what he wishes provided that he complies with regulator-defined constraints, usually defined by limit power flux densities at some local or distant geographic boundary.

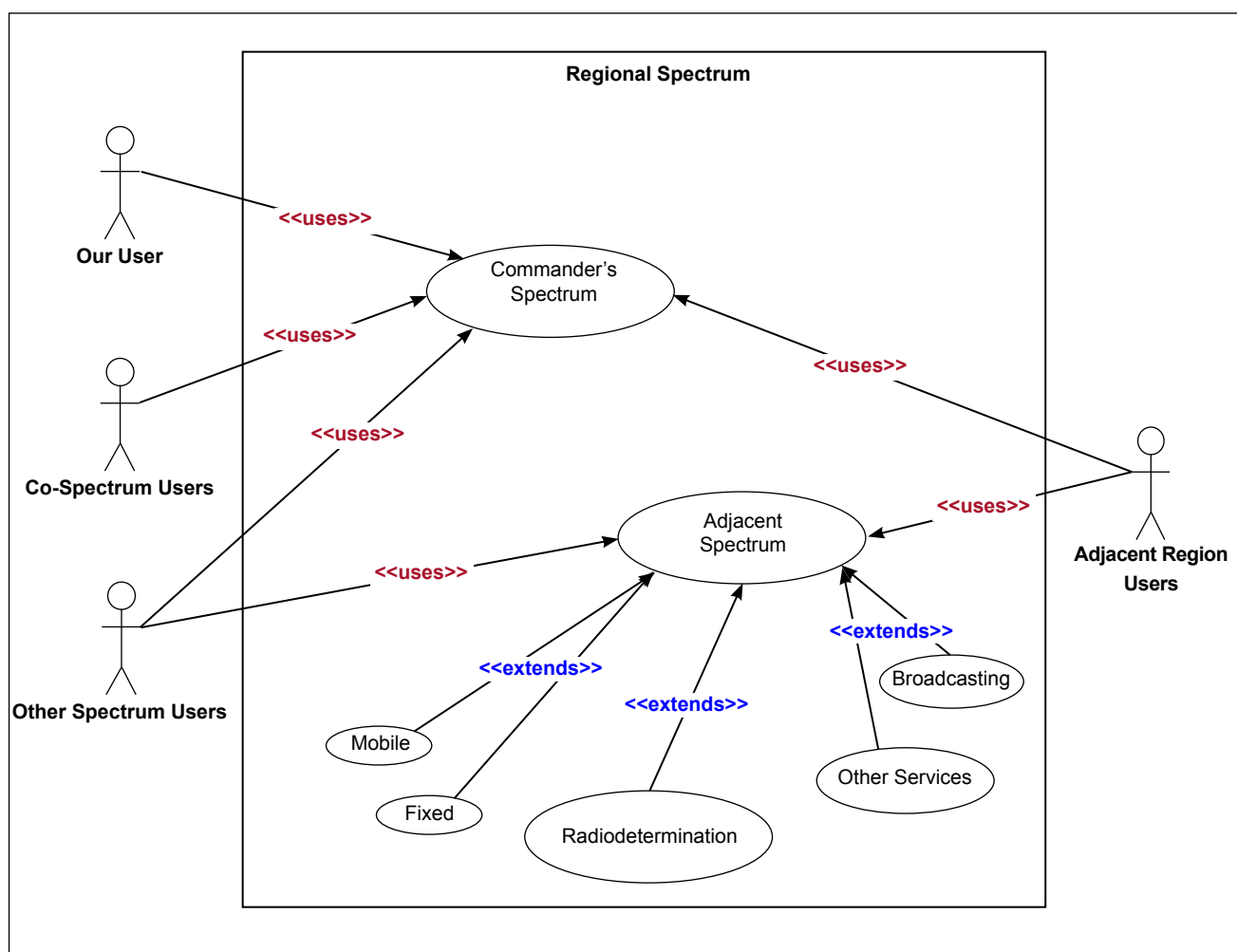


Figure 1 - Spectrum Use Case Model

common corporate aim are the Co-spectrum Users. They have the same commander as Our User but effectively compete in the spectrum (over which the commander has rights) for resource. Other Spectrum Users make their own way in the spectrum, appealing to the regulator or otherwise playing to achieve their own aims. They will share spectrum with Our User (mostly) where geographically separated and will be adjacent to Our User otherwise. That then leaves Adjacent Region² Users whom we imagine obey some rules in relation to Our User, thereby permitting the regions to coexist in some sort of harmony.

This paper will start by defining what is needed in a successful spectrum use outcome. It will visit briefly the phenomenon of chance in this success, considering the factors that make spectrum use stochastic. It finally looks at how decisions can be made - and on what basis in this environment - and closes with a brief look at practicalities.

² Region is used generically to represent a different geographic area under a different spectrum jurisdiction.

What Chance Success

A usable assignment or allotment is one in which Our User can define the benefit he requires in running the service and application necessary for his business or mission. For a fixed link running 34Mbps we might want an availability of better than 99.99% of time during which we would enjoy a bit error rate of at least 10^{-6} . The path-related effects within the link system add to the effects due to interference to give the tolerable outage (100-99.99%). The two are uncorrelated and hence in probability terms multiply to give the maximum degradation demanded of 0.001%. An assignment or allotment made that permitted this aggregate outage to be achieved would be a successful one. Conversely, one resulting in a higher than demanded outage would be deemed to be unsuccessful.

Interference comes from several sources. Our example link makes use of a channel; a block of spectrum in which most but not all of its wanted energy is generated in the transmitter and received by the distant receiver. Transmitters are imperfect. They also generate energy on adjacent blocks for considerable frequency spacing from the wanted block and this appears as noise to other receivers not on the wanted channel. Receivers are likewise imperfect. They are also sensitive to energy outside the wanted channel and again this appears as noise. Interference therefore comes from three sources: from other co-channel users (generally some geographical distance away) and from two mechanisms by which adjacent channel users create noise.

To explore interference briefly but fully, we must understand the effect of distance between victim receiver and culprit (interfering) receiver. Co-channel users need to be a long distance apart for signal levels to fall to such low levels that they no longer are considered contributors to interference. Adjacent channel users need to be close for there to be contribution though we should note that the higher the power, the longer away they must be, effectively countering this rule.

Potentially significant signal levels from culprit to victim vary considerably with time, locations and activity level. The argument so far has been that harmful interference is only permissible for very much less than 0.001% of time for our link system above. This means that interference comes from players located in the same geographic space with low activity and from those spaced several hundreds of kilometres away benefitting from seldom-occurring favourable propagation effects in the troposphere. The actual distance beyond which signals can be ignored depends on many system factors and is beyond the scope of this paper. For a working distance we might assume 200km, requiring us to consider culprits well beyond the horizon. Whether Our User is interfered or not depends on many stochastic effects and we must therefore talk in terms of probability to express the argument further.

We have established that any signal must be above a threshold before it will actually appear harmful. Signals do, however, aggregate and it may be as damaging to have contribution from a plethora of low-level signals as any one large one. This threshold that links back to percentage degradation or outage manifests as a nuisance field. If breached it is, as an aggregate, harmful. As argued above, it is determined by a number of stochastic parameters. Figure 2 shows on what the nuisance fields from each of the players depends.

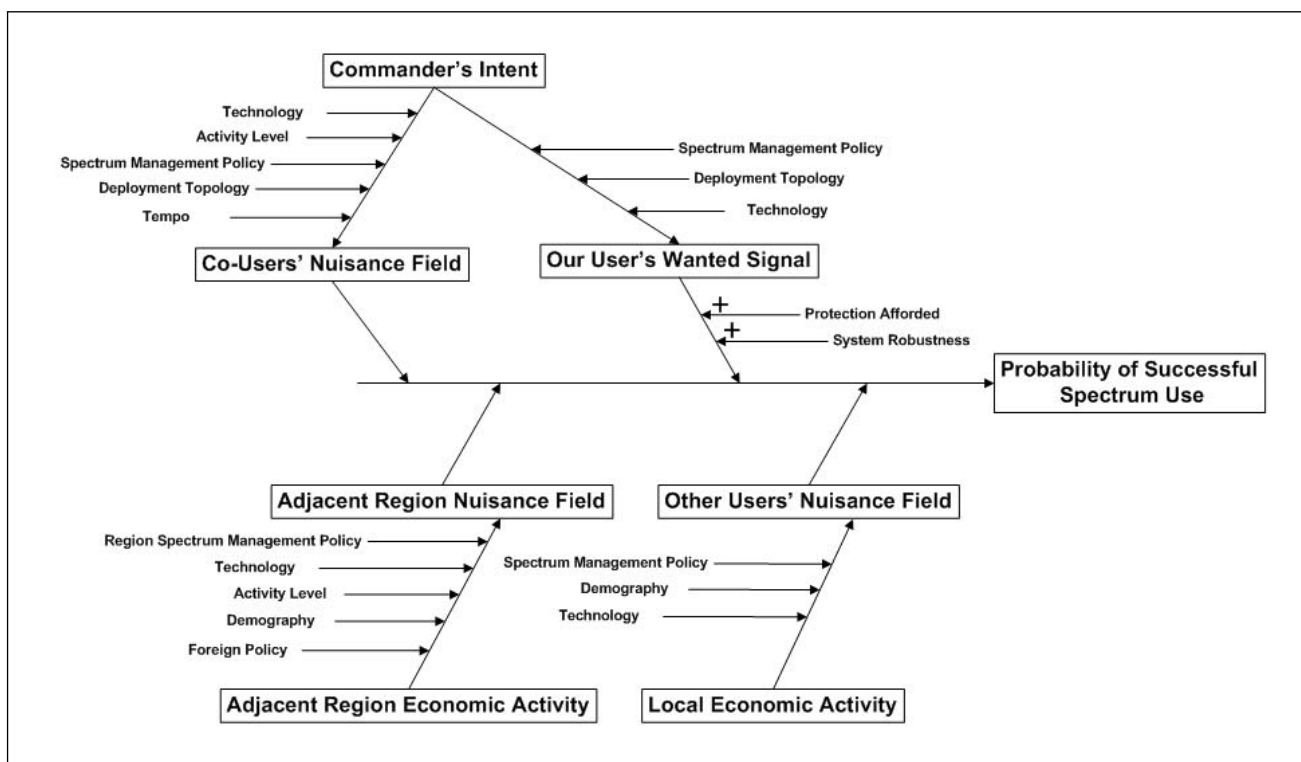


Figure 2 - Cause and Effect of Nuisance Fields

There are a number of generalisations in this diagram since no distinction is made between civil and military spectrum, thereby allowing all fields not associated with the 'commander' to be caused by economic activity. The fields caused by Our User and his Co-User colleagues depend on what we have determined as the 'commander's intent': in other words what he wants from the mission and what spectrum dependent devices he needs to deploy on whatever spectrum.

If we define the Probability of Successful Spectrum Use as $P(\mathbf{s})$, and consider the influence that the nuisance fields have on this mathematically, then we can develop an expression for spectrum management by relating this to commander's intent through the various probabilities. Nuisance fields degrade and hence we must remember that $P(\mathbf{s})$ will depend on one minus the probability of each individual field causing harmful interference designated.

Consider the effects of each of the legs of the cause and effect diagram individually. Our User is potentially interfered by a nuisance field from his colleagues co-channel

or adjacent. Let $\mathbf{P(c)}$ define the chance that this field exceeds its threshold. He is also potentially interfered by Other Users under the control of the commander but competing with him for spectrum resources. Let this be defined by $\mathbf{P(w)}$. In the same way, $\mathbf{P(a)}$ describes the adjacent region signals and $\mathbf{P(o)}$ those from other users within the region. We can therefore express the chance that Our User enjoys success in his use of the spectrum as:

$$\mathbf{P(s)} = 1 - [\mathbf{P(c)} + \mathbf{P(w)} + \mathbf{P(a)} + \mathbf{P(o)}] \quad \textit{Equation 1}$$

The probability of Our User gaining the spectrum quality from his channel when and where he needs it depends on one minus the probability that other spectrum users create excessive nuisance fields.

Using $\mathbf{P(s)}$ in Making Decisions

We have established that Our User will benefit from $\mathbf{P(s)}$ for his channel. He will also benefit from a $\mathbf{P(s)}$ for every channel or block in the spectrum that he may choose to make use of. We might designate this $\mathbf{P(sc)}$, the probability for the channel. The example of the link suggested that Our User had his own idea of what was needed to run his service and that this was set by the commander though a concept labelled Commander's Intent. It follows that there is likewise a probability desired by the commander of $\mathbf{P(ci)}$. We have therefore a probability of desired success and a probability of actual success caused by the nuisance fields from others. If Our User has need of another channel or block for a particular mission it follows that the decision as to which he should be assigned or allotted should be made to balance need and actual. Since a value of $\mathbf{P(sc)}$ can be developed for every channel or block it follows that a channel or block is a candidate for assignment or allotment if:

$$\mathbf{P(sc)} \geq \mathbf{P(ci)} \quad \textit{Equation 2}$$

If $\mathbf{P(sc)} < \mathbf{P(ci)}$ then Our User will not achieve the desired communications probability and this will contribute to mission failure. In order to make use of this expression practically, the spectrum manager (acting on behalf of the commander) must develop a matrix expressing the spectrum quality in bins across the spectrum of interest using nuisance fields from all contributors. That done, Equation 2 can be applied. Which channel or block is actually assigned or allotted will then depend on the policy employed by the spectrum manager under the commander's control; decision making such as most-constrained-first-assigned or equal-quality-for-all can be employed.

Practical Implementation

Spectrum assignment and allotment is a process that proceeds from application through analysis of the options to decision and conveyance of the decision to the applicant. It can be described by a process engineering diagram such as that shown in Figure 3:

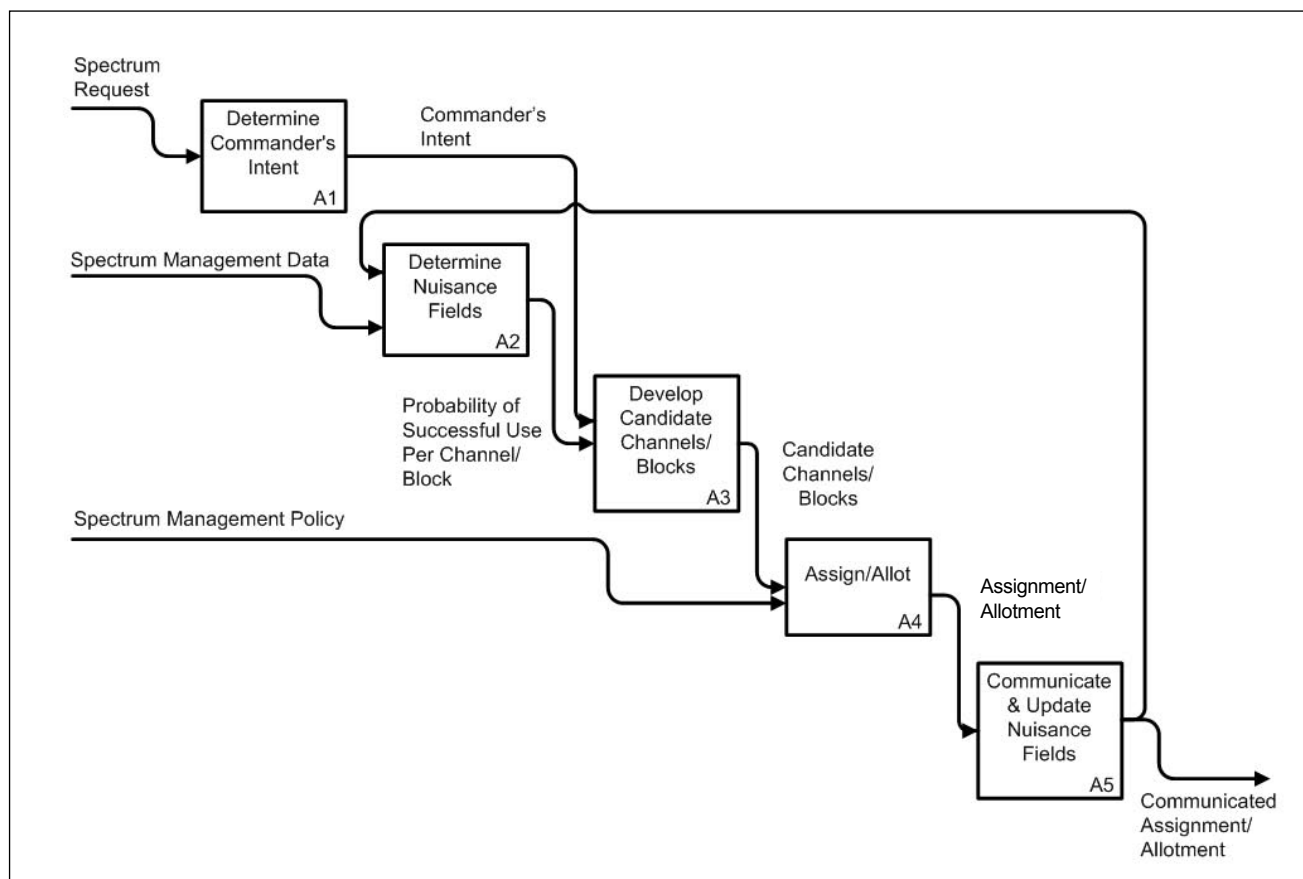


Figure 3 - Risk-Based Assignment/Allotment as a Process

The process develops a spectrum request into a communicated assignment or allotment for use by the requestor. Of particular interest is the need for spectrum management data from which to derive nuisance fields and from there the probability of successful spectrum management outcome. There is a popular misconception that in order to make spectrum management decisions, high-granularity data is needed. Spectrum management is a 'big handfuls, big map' science. We need to develop nuisance fields, rather than know precisely the characteristics of every station on the planet. We can default much. We can make assumptions; it is reasonable to assume that in the event that a memorandum of understanding has been signed between two nation states, the fields at the border are equal to the agreed level plus some small margin for installation error.

Reporting

As spectrum becomes overcrowded, the ability always to meet the commander's intent will diminish. Ultimately the commander will want to know whether spectrum availability is becoming (or is likely to become) a contributing factor in achieving his missions. Reporting in spectrum management has always been difficult. As engineers, we have always been inclined to report in terms of decibels and Watts. With risk-based spectrum management, all that matters to the commander is where his intent is not met. This leads to a report of the form shown below:

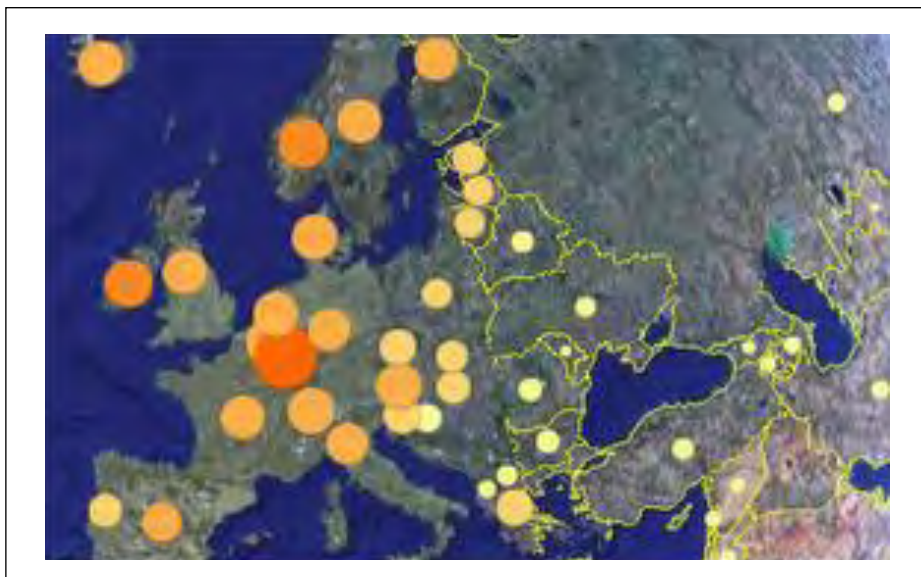


Figure 4 - Simple Red-Amber-Green Reporting of Intent Met

In this diagram green might indicate all assignments/allotments in a particular frequency range where the commander's intent has been met. In this display this has been suppressed as not being of interest. The only things that need be shown are the users where commander's intent is not met – amber and red showing degrees of problem in meeting the requirement. In a little-constrained spectrum the view would be blank. In a heavily-constrained spectrum it would be frequently red and amber.

Summary

This short paper has developed a concept that, for each spectrum user, there is an associated chance that he will be able to derive the benefit he expects from his spectrum assignment or allotment. This chance depends on other spectrum users both overlapping his frequency bandwidth and adjacent to it. It introduces the concept that some higher authority (called the 'commander') cares and expects his users to have at least a given threshold of success.

The logical use of the method therefore that the commander will demand high chance of successful spectrum usage to his highest value assets with lower chance given to those with more routine or threatened roles. The actual chance of success can be developed for every channel/block. This can be compared with the chance required by the commander. If the commander is to be satisfied, then the channel or block becomes a candidate for assignment.

The paper then goes on to show how this might be reported, breaking the mould by proposing a simple method of display when compared to the engineering displays more common in the subject.

The Author

John Berry is InterConnect Communications' Director of Spectrum Services and a radio communications expert with 30 years' experience in the mobile, fixed and broadcast radiocommunications industries, military radiocommunications and in radio spectrum management. The holder of a BSc in Electrical and Electronic Engineering, a BA in European studies and an MBA majoring in technology management, John is a Chartered Engineer and a Fellow of both the Institution of Engineering and Technology and of the Chartered Management Institute. John's role within InterConnect is to lead the development of the spectrum services product line. In this he manages major spectrum management projects and is an active consultant across the spectrum management domain and in wireless network design and implementation.

Prior to joining InterConnect, John spent some 13 years as Managing Director of ATDI Ltd, leading a series of major radio and spectrum management consultancy and software engineering projects which contributed hugely to Europe's telecommunications infrastructure and spectrum management policies. Prior to that, he acted as Business Unit Manager for MEL Communications (part of Thales Communications), establishing a civil products group within this military systems integrator majoring on spectrum monitoring, spectrum management and communications planning. John has also served in product development and marketing management roles for Maxon and Philips, covering product design, systems engineering and network planning.

John has presented some 60 technical papers and 20 technical/management workshops across Europe on spectrum-related topics, and is a patent holder in radio measurement techniques.

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InterConnect Communications

InterConnect Communications is a wholly-owned subsidiary of Telcordia Technologies Inc., based in the United Kingdom, and a leading provider of consultancy services on spectrum and wireless technology issues.

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- The development of frequency assignment processes, including mobile spectrum licence awards;
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