5

Value Creation and Migration in Adaptive and Cognitive Radio Systems

Keith E. Nolan[1], Francis J. Mullany[2], Eamonn Ambrose[3], and Linda E. Doyle[4]

[1] Centre for Telecommunications Value-Chain Research, University of Dublin, Trinity College, Dublin 2, Rep. of Ireland, keithnolan@mee.tcd.ie, +353-1-8968443
[2] Alcatel-Lucent, Bell Labs Ireland, Blanchardstown Industrial Park, Blanchardstown, Dublin 15, Rep. of Ireland, mullany@alcatel-lucent.com, +353-1-6924245
[3] CTVR, National Institute of Technology Management, University College Dublin, Dublin, Rep. of Ireland, eamonn.ambrose@ucd.ie, +353-1-7161741
[4] Centre for Telecommunications Value-Chain Research, University of Dublin, Trinity College, Dublin 2, Rep. of Ireland, ledoyle@tcd.ie, +353-1-8962567

5.1 Introduction

In this chapter, the concept of a telecommunications value-chain is developed, leading to an exploration of the many ways in which the value-chain can be altered by reconfigurable software-defined radios, cognitive radios, and cognitive networks.

Innovative and emerging wireless communications applications involving the use of adaptive and cognitive radio technology ideally attempt to maximize and capture the value to the users while reducing the manufacturing, deployment, and upgrade costs incurred by the manufacturer and service provider(s).

The telecommunications value-chain creates consumer value through the provision of communication services over fixed and wireless networks. Porter [1] explains how value-chain analysis "divides a firm into the discrete activities it performs in designing, producing, marketing, and distributing its product". Within the telecommunications value-chain, the design and development of software-defined and cognitive radios has the potential to significantly effect consumer value. The purpose of this chapter is to firstly develop the concept of a telecommunications value-chain and secondly, explore the many ways in which the value-chain can be altered by adaptive and reconfigurable Software-Defined Radios (SDR), Cognitive Radios (CR), and cognitive networks.

H. Arslan (Ed.), Cognitive Radio, Software Defined Radio, and Adaptive Wireless Systems, 145–159.

In order to put this chapter into the correct context, Section 5.2 is a brief recap of the terms cognitive radio and cognitive networks from the authors' collective viewpoint. Section 5.3 introduces the concept of a value-chain. The topics of value-creation and value-migration are explained in Section 5.4. Section 5.5 develops an economic value model considering the net present value of a network of nodes with cognitive functionality. Section 5.6 outlines four examples and case-studies that aim to help the reader strengthen their understanding of the value-chain concepts presented in this chapter. Section 5.7 concludes. For a deeper understanding of the the concepts presented in this chapter, the reader is directed to relevant references, which are provided in the bibliography.

5.2 Cognitive Radio and Networks

For the purposes of this chapter, it is useful to define what the authors refer to as a cognitive radio and a cognitive network. Cognitive radio can be described as a node in a network with an ability to form an awareness of its environment and context, make decisions and inferences from this information combined with knowledge of the user's objectives, act in a manner that attempts to accomplish the user's objectives, and optionally learn from these experiences for possible use in the future [2, 3]. The foundation of a cognitive radio is essentially a wireless communications stack capable of being dynamically reconfigured. This may be implemented using a software-defined radio, which is a wireless device where some or all of the physical layer (PHY) and the rest of the communications stack is implemented in software, or can be configured using a software mechanism. Cognitive functionality may have an influence on all or many of the layers in a communications stack and is not just limited to the PHY only, however.

A cognitive network is a network of nodes with cognitive functionality [4,5]. These nodes may have the potential to form an awareness of each other and even combine their resources and complementary expertise in order to perform as a collaboration and even in unison as a team [6].

5.3 The Value-Chain

The term *value-chain* is used to describe the interconnected stream of organizations, activities, and capabilities that combine to generate value for customers through the production of goods and services [7]. It is a refinement of the supply chain concept, where the focus is on value generating elements as opposed to procurement and logistics. Porter identified how the activities of organizations in the chain, and in particular, interactions between organizations, could be the source of sustainable competitive advantage through the ongoing creation of customer value and through continuous reduction in the cost of creating that value. Much of the effort of supply chain or value-chain management is devoted to identifying or predicting sources of customer value, and in maximizing delivery of that value at minimal cost in the chain.

Value is typically measured in terms of revenue for the organizations within the chain, and in terms of utility for the customers. Utility is the economic term for the satisfaction derived by customers in the consumption of goods and services. In value-chains, any party that gains utility from the chain activities (whether by consumption or other means) should be considered a customer. Organizations contribute to the value of the goods and services through their activities, and generate profits by minimizing their costs and maximizing revenue, i.e. maximizing the value provided to the next organizational downstream in the chain. For the customers, the goods and services are consumed, generating utility for the customers in excess of the cost. In cellular wireless markets for example, the value of advanced high-speed video download services may not be evident to the end user until after the handset is paid for. The cost of the advanced handsets may be subsidised by the service provider or even the content provider in order to encourage the uptake of these services. With push advertising on a cellular phone being used to pay, in whole or in part, for a service consumed by the handset owner, both the advertising company and the ultimate end user are customers.

Figure 5.1 is an example of one value-chain that can be associated with a cognitive radio system. The value generating elements in this chain include cognitive functionality, dynamic spectrum access, ease of communication, and abilities to develop and deploy new applications and services with relative ease compared to a traditional fixed-architecture system model. The cognitive functionality element of this chain offers value by combining awareness, decision-making and learning capabilities with the ability to rapidly implement change in both reactive and preemptive modes of operation based on current and historical knowledge of the user's habits and anticipated communications needs. This allows the burden of modification and optimization of the system performance to be moved away from the user to the device itself.

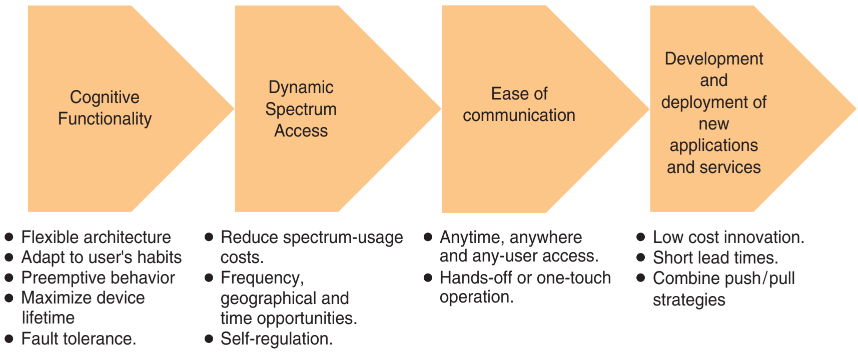

Fig. 5.1. Example of one value-chain associated with a cognitive radio system.

Cognitive functionality also provides a way to work around and fix faults that may develop in the device. In addition, this functionality can help maximize the operating lifetime of the device itself by attempting to reach a compromise between the available node resources (e.g. remaining energy, available spectrum, RF hardware) and communications demands placed on the device by the user. The value that can be derived from a more dynamic approach to spectrum access as featured in the second element of Figure 5.1, is that the probability of successful wireless communication can increase dramatically. Dynamic spectrum access techniques combined with cognitive functionality offer a means of exploiting unused or under-utilized *whitespace* spectrum segments while attempting to ensure that incumbent and non-cooperative users experience minimal interference. This ability enables the cognitive node to take advantage of the geographical and time-of-day variations in spectrum usage patterns for its own needs. From the user's perspective, the ability to communicate becomes a feature that is taken for granted as the underlying cognitive functionality and dynamic spectrum access technologies can automatically manage the spectrum access requirements. The third element of this value-chain is therefore the ease of communication that users can experience regardless of the geographical location, movement patterns, time of day, and user's technical knowledge (or lack thereof). The fourth and final element in this simplified value-chain is the value that can be derived by combining all of these features to enable both the service providers and users to quickly develop and deploy innovative revenue-generating services and applications. These new services can be both pushed onto the market by the service provider or user, and optimized quickly based on the subscriber's interest in these services in order to maximize the generated revenue.

In addition to the consumers, other non-consuming customers such as a telecommunications regulator may get value from the chain. The regulator gains utility from the creation of a telecommunications regime that meets the defined regulatory standards, which may be considered a measure of societal value. For example, frequency spectrum regulators may reserve spectrum for emergency services because of the value of such services to society. Communications regulators including the Commission for Communications Regulation (ComReg) in Ireland, also impose terms and conditions on telecommunication network operators as regards the percentage of the population covered by basic services such as mobile voice connectivity.

It can be difficult to quantify non-monetary value to society. However, when discussing value creation or migration, the involvement of multiple customers with different perceptions of value must also be considered. These different perceptions of value may also be dependent on the priority of that service according to the user. An example of this challenge is attempting to quantify the value created in public safety scenarios where through the provision of telecommunications services, the potential to more efficiently locate and co-ordinate the rescue of survivors in a disaster area can be increased. In this scenario, the potential of telecommunications is of higher societal value than the ability to establish a high quality video link. It can be difficult to quantify such societal values in economic terms, which poses a challenge for value-chain models.

The value-chain perspective can be summarized as follows:

- There are multiple customers in the chain for whom value can be created.
- Value is ultimately defined by the utility gained by consumers and other customers. Value is created when the utility of the ultimate customer(s) is increased.
- Within the chain, profits may be increased either by reducing cost or by increasing revenue gained from another organizational, even though ultimate customer value is not improved. In this way, value can migrate along the value-chain.

5.4 Value Creation and Migration

Value is not a static entity. The total value in a chain is the sum of the utility of the various customers, each having a unique perspective which may be constantly evolving. The challenge for organizations in the chain is to identify opportunities for value creation, and to ensure that they capture that value through increased profits. However, this newly created value is not easily captured – Sylwotzky [8] and Ng et al. [9] show how the dynamics of value migration within the value-chain are complex and difficult to manage. Fine [10] identifies the concept of clockspeed – the rate of change within an industry as a key driver of the dynamics of value creation and migration. Clockspeed can be measured in terms of product life cycle but it is not necessarily a fixed parameter within any value-chain. For network operators, product life is of the order of years while at the downstream end of the chain for the wireless communications application developer it might be weeks. Hence value will potentially migrate more quickly between value-chain members downstream.

The strength of a cognitive radio system is the flexibility and adaptability that it offers. This flexibility can be exploited to provide attractive features for both a service provider and user. One of these appealing features of a cognitive radio-based system, therefore, is that it has the potential for value creation and migration. A cognitive system that can adapt to the local environment, scenarios, and business models has a high value to both the service provider and user. Furthermore, this value can actually migrate either intentionally or unintentionally.

Any activities which generate increased value to any of the ultimate customers of the system are seen as value creating activities. This may be activities internal to a firm, or between existing firms. It may be the introduction of new technologies, or the deployment of existing technology in an innovative manner. Value creation, while desirable, is not always deliberate. In the European market predominately, the vastly popular mobile phone Short Message Service (SMS) in Global System for Mobile Communications (GSM) is one example of this. This facility was provided as a minor addition by phone manufacturers which has become highly valued by customers – a mechanism known as *market pull innovation.*

On the other hand, innovation can occur through *technology push*, where new technologies are offered to the market in order to stimulate demand for the associated value proposition. As an example, the availability of multimedia messaging is not generating the hoped-for fast sales growth as customers do not as of yet, assign significant value to the feature. It is the customer perception of value that is key, and no value creation takes place until the customer adopts the technology. From a service provider or innovative user viewpoint, the value of a cognitive radio and network is that new and innovative services can be offered to the public relatively quickly and on a trial basis in order to probe the market's interest in that feature. In order to initiate and sustain this activity, flexibility, an open development platform, and rapid low-cost prototyping, are necessary. The value-chain illustrated in Figure 5.1 and introduced in Section 5.3, points out that potential value from both *technology push* and *market pull* mechanisms can be leveraged in a cognitive radio system as it is designed to both handle, and facilitate change.

Moving towards a more forward-looking cognitive radio network scenario, the ability to collaborate and combine resources with other cognitive radio devices may not be of high value to a user wishing to only transmit a file to a colleague. However, the ability to exploit the potential collaboration and resource-combination features of a cognitive network in order to establish an emergency communications network in the event of a natural disaster may be of very high value to those directly affected by this disaster.

Value migration is therefore critical to firms in the value system, who wish to capture maximum value at minimum cost. The migration of value can be controlled, but not fully – it is often beyond the power of a single firm to influence. Firms must therefore understand value in the context of the complete supply chain. Two questions are key to a firm's strategic analysis of value: "When value is created who captures this and how can this be achieved?" and "when value changes (a change of target market and customer profile, for example) how to hold onto value?".

5.5 Economic Value Model

The associated microeconomics can be represented in terms of a value-chain, i.e. the sequence of suppliers and customers that are required to deliver a product or service to the end user of (in this case) communications. The value-chain can stretch from the component supplier, to the system integrator, to the service provider, and on to the end user.

Figure 5.2 is a graphical representation of a three-stage supply chain. In the context of this chapter, A could be network operators and B, Mobile Virtual Network Operators (MVNO). The end users are denoted by C. Equally,

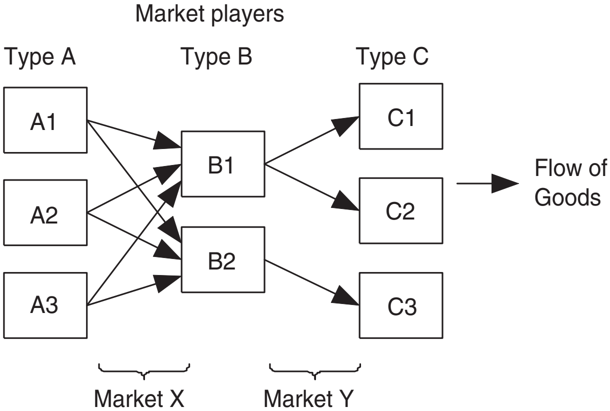

Fig. 5.2. Illustration of a three-stage supply chain.

A could be the primary spectrum users and licensees, and B wireless access operators exploiting spectrum opportunities. In this scenario, the end users, C could also act in an opportunistic manner, favoring one operator or unlicensed and free spectrum access scheme over another depending on its information conveyance needs and context. Many combinations are possible, but a viable value-chain requires that all players in the chain are achieving a surplus in their respective transactions.

Figure 5.2 is only a representation of the inter-relationships involved. A complete representation of the value-chain would include service/product capacities, market structure, measures of customer value, and market player strategies.

Regarding the latter, companies may build up business models to predict their performance. In this section, we do so for a network operator, while noting in its most general sense, a "network operator" could be as simple as a homeowner with a Wireless Local Area Network (WLAN) access point allowing access to users in the vicinity.

One typical measure of the potential success of a future project is that of net present value, i.e. the profitability of a project in today's unit of currency. Assuming a discount rate of d for future expenses and revenues and a project life of N_T years, then the Net Present Value (NPV) is given by Equation 5.1, where N_U is the number of subscribed users and $r_U(n)$ is the Average Revenue Per User (ARPU) in year n. The total CAPital EXpenditure (CAPEX) for network infrastructure is c_I, and c_S is the price paid for the spectrum used. The average handset subsidy per user is denoted by c_U and the OPerational EXpenditure (OPEX) for the network in year n is denoted by $o_I(n)$.

The NPV can therefore be described as

$$\mathrm{NPV} = N_U \sum_{n=1}^{N_T} \frac{r_U(n)}{(1+d)^n} - c_I - c_S - N_U c_U - \sum_{n=1}^{N_T} \frac{o_I(n)}{(1+d)^n} \tag{5.1}$$

While all of the above parameters depend on the interaction in the marketplace with other network operators, suppliers and customers, the parameters N_U and $r_U(n)$ are explicitly related by the price demand curve. This is in turn, heavily dependent on the market conditions.

Other metrics exist for measuring the value of a project. One commonly used is that of Return On Investment (ROI). The ROI is the compounded annual percentage interest rate that would have yielded the same profit on the invested capital.

In order to help the reader to gain a better understanding of how the costs, number of subscribers and revenue are interrelated, consider the following simplifications and (fictitious) sample values. Assume that the number of subscribers, $r_U(n)$ and OPEX for year n, $o_I(n)$ are constant over time. Furthermore, assume that this OPEX, $o_I(n) = o_I$ can be broken down into network OPEX (usually expressed on a per annum basis as some fraction k of overall CAPEX), and per-subscriber OPEX, o_U (billing costs, customer support costs, etc.). Figure 5.1 can be simplified as follows; let

$$\hat{N}_T = \sum_{n=1}^{N_T} \frac{1}{(1+d)^n} \tag{5.2}$$

Hence the NPV, as originally stated in Equation 5.1, can now be described as

$$\text{NPV} = N_U \hat{N}_T \left(r_U - o_U - \frac{c_U}{\hat{N}_T} \right) - \left\{ c_I \left(1 + \hat{N}_T k \right) + c_S \right\} \tag{5.3}$$

Consider a scenario where there is \$200 million of CAPEX; \$100 million of spectrum license fees; network OPEX of 5 % CAPEX per annum; subscriber OPEX of \$20 per annum per user; average \$50 of handset subsidy per user; one million users; an ARPU of \$150 per annum; a discount rate of 5.5 %; and a project life of six years ($\hat{N}_T \approx 5$).

This would yield a healthy NPV of approximately \$250 million.

The above model captures the value seen by one type of player in the chain only, namely an operator. It allows one to make qualitative statements as regards the value-chain impact of cognitive radio for an operator. These are explored in further detail in the next section.

Models can be created for other players, e.g. users, content providers, etc., although some parameters can be difficult to quantify, e.g. value to end users. For yet other players such as national telecommunications regulators, it is difficult to create the model itself, given the complex mix of societal and market impacts involved. In order to put these challenges into relevant contexts, some scenarios involving different players' interpretations of value are presented in the following section.

5.6 Example Scenarios

This section describes some scenarios that aim to help the reader to gain a better understanding of the concepts described in this chapter. These scenarios involve a communications network where technological change can create opportunities for new business models. Sections 5.6.1 and 5.6.2 describe how users can gain more value through increased communication coverage and ease of use, which has potential for increased ARPU for the operator. Users may have the potential to gain financial credit from the operator by contributing the capabilities and features of their cognitive radio devices to the network infrastructure, as described in Section 5.6.3. Thus, value is increased and this migrates as the benefits are shared between user and operator. Value is not limited to the user and operator spaces but can have implications for external third parties also. As an example of this, a scenario examining value from a spectrum regulator viewpoint is outlined in Section 5.6.4.

5.6.1 Simplified Man–Machine Interface

The concept of a very simple user interface was introduced in Section 5.3. To the average non-technically minded customer, the potentially greater freedom of communication regardless of location and trajectory, using a system that is more in tune with their daily behavior patterns is what they may perceive as a high value feature. The power of cognitive radio also lies in the ability to provide a very simple interface to what can be a very complex system, where ideally the user requires no technical knowledge in order to operate the device. This is referred to in this chapter as *one-touch operation.* This customer may not place a high value on the cognitive functionality itself (or even care), but if this functionality results in universal *one-touch* or entirely hands-free operation through a simplified context-related MMI (man–machine interface), requiring little conscious effort on their part, then a potentially valuable product may be realized.

The potential benefits of cognitive radio technology to the daily lives of consumers are enormous. An ability to anticipate the wireless communications needs of the users and take preemptive action by seeking out the either the most robust or economical means of information conveyance is attractive. In addition, the ability to establish and maintain a communications link regardless of location, trajectory and wireless environment is also a desirable feature. Developing a cognitive radio device capable of one-touch or even totally hands-free and fault-tolerant operation may require increases in CAPEX and handset subsidies to help promote adoption of this system. However, the potential of this device is that it may actually help increase the ARPU as communication becomes an ability taken for granted and is used more as a result. The simple interface and increased ease of use could encourage more new subscribers to adopt the use of this technology.

We consider the economic value model described in Section 5.5 with the following sample (and fictitious) adjustments to the original set of figures for a future project involving the use of cognitive radio. In this scenario, we make conservative assumptions that the development of a fault-tolerant cognitive radio with a simplified man–machine interface requires increasing the original CAPEX (CAPEX = $300 million) and the handset subsidies required to promote initial uptake may also have to be increased to $100 per device. However, attracted by the increased ease of use and reliability, this technology may increase the customer base from 1 million to 1.2 million subscribers. In addition, the 'taken for granted' nature of the ability to communicate, combined with the increased ease of use, may be expected to result in an increase in ARPU from $150 to $175. The network OPEX is retained at their original values, although the subscriber OPEX is reduced to $15 per user as the fault-tolerance and simple MMI reduces the customer support costs. The NPV in this case is $365 million, an increase of $115 million. Although these are example figures, a key observation is that even considering the effects of a significantly increased CAPEX and handset subsidies, the NPV is still significantly greater than zero, indicating that this may be a viable project.

5.6.2 Dynamic Spectrum Access

Cognitive radio is popularly associated with enabling more efficient use of frequency spectrum. Certainly, cognitive functionality in the form of awareness, reasoning, learning, and frequency agility abilities are necessary to detect and exploit spectrum opportunities. The ability to relinquish this spectrum when the information transfer is completed or when a user with a higher priority appears in the same spectrum segment is also a necessary feature. More efficient use of spectrum also means being able to accommodate more wireless devices operating in the same spectrum segments without causing interference to each other. This interference-free coexistence ability can therefore increase the potential number of subscribers, N_U, in a network of cognitive nodes.

Figure 5.3 illustrates this concept where a network of cognitive radio devices (B) operating on a secondary opportunistic basis, co-exist with the legacy primary user network (A). The legacy users may or may not have cognitive functionality and are referred to as *non-cooperative* users. This scenario can be realized if the secondary users can avail of the *white space* spectrum (unused spectrum in the primary user spectrum allocation) [11] or transmit packets when the primary user nodes are estimated to be inactive. It is also feasible that an increased number of nodes with cognitive functionality could be supported in the same spectrum segment, and be part of the same network compared to a network of nodes without cognitive functionality [12]. In this figure, the secondary users exploit the unused spectrum segments, shown in green, on either side of the primary user spectrum illustrated in orange.

Dynamic spectrum access is of value to the average customer if this ability can enable the desirable *always-connected* feature of a cognitive radio.

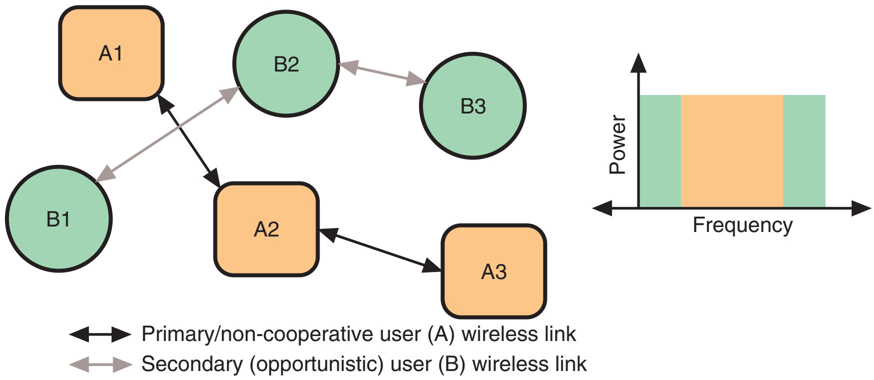

Fig. 5.3. Illustration of how the number of potential users can be increased in a spectrum segment if secondary opportunistic usage, operating on a non, or minimal interference basis, can be supported using cognitive radio technology. The primary (or *non-cooperative* users) and secondary opportunistic users, and their spectrum occupancies, are illustrated in orange and green, respectively.

The ability to utilize only as much spectrum as is deemed necessary in order to facilitate the required information transfer, or seek out spectrum with a lower cost of usage may result in extra added value to this customer in the form of lower costs in a *pay to use* spectrum market regime.

The ability to avail of unlicensed spectrum for short range, lower priority or interference-tolerant communication services helps to reduce the demand for licensed spectrum segments. This is an obvious benefit for the operator. By reducing the spectrum-usage costs while retaining the same (or greater) ARPU, a positive change in the NPV can be observed.

Considering the previous example in the context of a future cognitive radio project employing dynamic spectrum access technology, three potential scenarios exist:

- The operator may either choose to halve their current licensed spectrum allocation, thus reducing the cost of spectrum licenses, c_S.
- The operator may choose to retain their current licensed spectrum allocation but avail of unlicensed spectrum also, thus increasing the total potential available spectrum. In this case, c_S remains static.
- The operator may choose to retain exclusive usage of part of the licensed spectrum allocations, and lease the remainder to other operators for opportunistic usage in return for a flat or per-usage fee. The result of this is that the cost of spectrum licensing is reduced.

The consequences of these three approaches are that either the cost of spectrum, c_S, decreases and/or the ability to accommodate more users, N_U, increases. If the initial CAPEX estimate accounts for cognitive radio devices capable of both licensed and unlicensed spectrum usage, then it is feasible that the modification of the operator's existing business model to lower costs and increase revenue in this manner requires a relatively inexpensive software upgrade, or a change in spectrum-usage policy, governing the behavior of the cognitive radio subscriber device.

Using the example (and fictitious) values in the previous scenario, consider the scenario where the required CAPEX, c_I is \$300 million, subscriber OPEX, o_U is \$15 per user per annum, and the expected ARPU, $R_U(n)$ is \$175 (assuming that the lower cost of spectrum usage is not passed directly to the user). In addition, the number of subscribers, N_U, is 1.2 million, the cost of spectrum licensing, c_S is reduced by \$25 million to \$75 million, and the handset subsidy and discount rate remain unchanged (i.e. $c_U = \$100$, $k = 5.5\,\%$, and $\hat{N}_T \approx 5$). In this example, by reducing the cost of spectrum-usage by \$25 million, the NPV is \$390 million. This represents an increase of \$140 million over the original non-cognitive radio oriented scenario.

5.6.3 Message-Relaying and Micropayments

Customers place value on the ability to communicate. In the case of a cellular network, this ability can be lost if a customer's device is out of range of a base station. A network operator wishes to maximize revenue by accommodating users out of range of base-station range without having to significantly upgrade the current network architecture (and as a result, increase c_I and o_I). In addition, it may not always be possible to erect or move base stations to where they are deemed necessary, and human behavior patterns and concentration of users in a given geographical area may also change over time (e.g. due to new housing scheme, new roads, and rail links). In order to capture the potential revenue from these subscribers using the existing infrastructure, one option is to enhance the subscriber device abilities. In addition to the operator's main goal of increasing the revenue generated by the customers increasing demand wireless connectivity in a region, they may desire to preparing themselves for the future roll out of new wireless communications-based services. In order to do this, the operator must try and accommodate more subscribers, maximize the use of the existing network infrastructure, and ideally avoid further capital expenditure on network expansion.

One of the attractive features of cognitive radio technology also lies in the ability to deploy new services/communications abilities without incurring a significant increase in the CAPEX and OPEX. These new services may involve changing the way the existing network infrastructure is used to convey information. In this scenario, message-relaying is used to increase the effective coverage of base stations and also increase the number of subscribers that can communicate using this base station.

Cognitive radio devices can act as message relays in parallel to the regular audio/video/data communication services. Customers out of range of a base station but within range of another customer's cognitive radio device can therefore route their messages and voice calls through one or more available

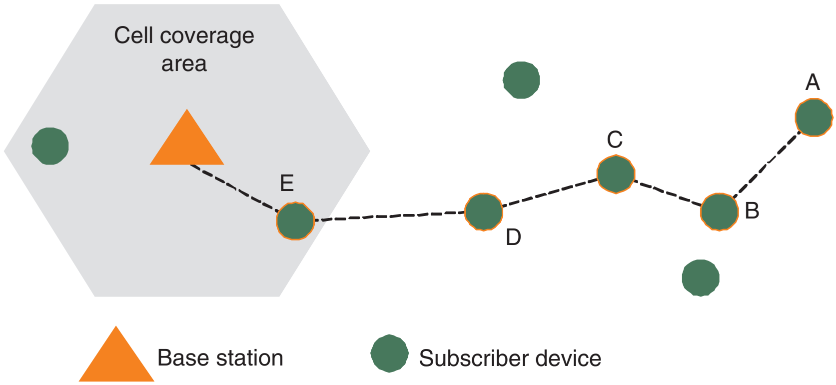

Fig. 5.4. Conceptual illustration of a message-relaying for nodes out of base station coverage.

nodes until the messages reach a base station and can continue through the rest of the network. By enhancing the cognitive functionality of each node, greater numbers of potential subscribers, N_U, may be supported per year without having to significantly upgrade the network infrastructure. This may help to keep c_I at a static or slowly rising level thus increasing the potential revenue.

This message-relay in a cellular network context is illustrated in Figure 5.4. Message traffic from **Node A** is relayed by **Node B**, **Node C** and **Node D** to **Node E**. Node E is within the base station coverage area and can complete the wireless communications link.

This method used to expand the capabilities of each consumer device can take the form of an over-the-air upgrades allowing each device to reconfigure as a message relay when required. Each device may choose to act exclusively as a message relay when not in active use by the customer, possibly encouraged by the prospect of payment for this service.

From a consumer standpoint, extra value may be extracted from the use of cognitive functionality in radio systems by being able to collect payment in return for relaying messages from other users. This small share of the total payment is referred to as a micropayment [13]. This incentive could help the 'always-connected' value of a cognitive network by encouraging devices to act as relay nodes in an ad hoc network (becoming part of the network infrastructure) thus helping to increase the possibility of communication.

However, the increase in network usage (e.g. through increased number of users N_U) will be offset by the degree to which micropayments reduce the ARPU, r_U.

5.6.4 Spectrum Regulator Value

Interference-free co-existence and more dynamic use of spectrum using cognitive functionality may be perceived as having value to an operator. As stated earlier, from a customer point of view, value is gained from these abilities if they enable the desired ‘always-on, always-connected’ experience, simplified MMI, etc. While it is useful for considering direct user and operator economic value, the NPV representation in this chapter does not account for this external third party value. An example of a relevant third party is a spectrum regulator, who may stand to gain from these features also but is not an operator or wireless user. From a value viewpoint, cognitive functionality could help shift some of the burden of regulation into the cognitive device and network space, as illustrated in the cognitive radio value-chain shown in Figure 5.1. Cognitive radio devices capable of operation in a non-interference manner and automatically adherence to the relevant regulatory policies helps to advance the concept of a self-regulation spectrum environment. While it is difficult to quantify the potential created value from a spectrum regulator viewpoint, it is feasible that self-regulation may reduce the need for active spectrum compliance testing. As a consequence, therefore, more time may potentially be allocated for carrying out other regulator activities. It is also possible that self-regulation can help support the argument for liberalization of the current spectrum licensing arrangements.

5.7 Conclusions

This chapter introduced the concept of a telecommunications value-chain and explored some of the many ways in which the value-chain can be altered by adaptive and reconfigurable software-defined radios, cognitive radios and cognitive networks. A description of how value can migrate and be created was also presented.

In order to help further illustrate the concepts described in this chapter, scenarios involving cognitive radio technology operating in a customer-centric network were discussed in terms of the impact on that model. The largest changes will be seen where significant improvements result in the services offered (e.g. improved coverage or simplified interfaces), since the ARPU or the number of customers may increase. Lesser value-chain impact will arise where there are changes in the internal operations of the network only, i.e. where impacts are confined to increasing handset subsidies or delayed CAPEX spend.

The business model allows one to predict the behavior of one operator. It does not directly describe the impact of competition from other operators. Thus, there are other significant impacts due to the introduction of cognitive radio that arise when the market structure itself changes. For example, if cognitive radio enables cheaper access to spectrum then new players may enter the operator market, increasing competition.

Ultimately, cognitive radio technology has significant potential to change how internal business models of the players interact with the market structures. The models and scenarios discussed here represent a first step in the analysis of the resulting value creation and migration.

Acknowledgments

This material is based upon work supported by Science Foundation Ireland under Grant No. 03/CE3/I405 as part of the Centre for Telecommunications Value-Chain Research (CTVR) at Trinity College Dublin, Ireland. The authors also wish to thank Stephen Wilkus of Alcatel-Lucent for his insights and comments.

References

1. Porter, M.E., *Competitive Advantage : Creating and Sustaining Superior Performance*, The Free Press, New York, 1985.
2. Haykin S., "Cognitive Radio: Brain-Empowered Wireless Communications", *IEEE Journal on Selected Areas in Communications,* February, 2005.
3. Fette, B. (Editor), *Cognitive Radio Technology*, Newnes, Aug. 2006,ISBN: 0-7506-7952-2.
4. Thomas, R.W., DaSilva, L.A., and Mackenzie, A.B., "Cognitive Networks", in Proceedings of the 1st IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, Baltimore, MD, USA, 8–11 Nov. 2005, pp. 352-60.
5. Thomas, R.W., Friend, D.H., DaSilva, L.A., and Mackenzie, A.B., "Cognitive Networks: Adaptation and Learning to Achieve End-to-End Performance Objectives", *Topics in Radio Communications, IEEE Communications Magazine,* December 2006.
6. Nolan, K.E., Doyle, L.E., "Principles of Cognitive Network Teamwork", in Proceedings of the 51st SDR Forum General Meeting and 2006 Technical Conference, Nov. 13–17, 2006, Orlando, Florida.
7. Nolan, K.E., Ambrose, E., and O'Mahony, D., "Cognitive Radio: Value Creation and Value Migration", in Proceedings of the 51st SDR Forum General Meeting and 2006 Technical Conference, November 13–17 2006, Orlando.
8. Sylwotzky, A.J., *Value-Migration*, Boston: Harvard Business School Press, 1996.
9. Ng, P.T.A., Lu, D., Li, C.K., and Harry Chan, H.Y., *Strategic Lessons of Value Migration in IT Industry.* Technovation 25, 2005, pp. 45–51.
10. Fine, Charles H., *Clockspeed: Winning Industry Control in the Age of Temporary Advantage*, New York: Perseus Books, 1998.
11. Cordeiro, C., Challapali, K., Birru, D., and Shankar, S., "IEEE 802.22: The First Worldwide Wireless Standard based on Cognitive Radios", in Proceedings of the 1st IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, Baltimore, MD, USA, 8–11 November 2005, pp. 328–337.
12. Nolan, K.E., Rondeau, T.W., Sutton, P., Le, B., Doyle, L.E., and Bostian, C., "Dynamic Spectrum Access and Coexistence Experiences Involving Two Independently Developed Cognitive Radio Testbeds" in Proceedings of the 2nd IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN 2007), April 2007.
13. Peirce, M., and O'Mahony, D., "Flexible Real-Time Payment Methods for Mobile Communications", *IEEE Personal Communications,* Vol. 6, No. 6, December 1999, pp. 44–55.