COGNITIVE RADIO: VALUE CREATION AND VALUE-MIGRATION

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ABSTRACT

This paper develops the concept of a telecommunications value-chain and explores the many ways in which the value-chain can be altered by reconfigurable software-defined radios, cognitive radios and cognitive networks. In cognitive radio terms, value creation can occur through increased functionality of devices, such as the always-connected-anywhere feature of a cognitive radio for example. This value can migrate within the value-chain according the context in which the device is operating in, and the time-varying objectives of the system. However, this newly created value is not easily captured and the dynamics of value migration within the value chain are complex and difficult to manage. The design, test, manufacture, certification, maintenance and evolution of software-defined radio and cognitive radios, and the subsequent implications for the value-chain are explored. In addition, a scenario involving a network of cognitive radios and the subsequent impact on the value-chain will be investigated.

1. INTRODUCTION

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 paper 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, cognitive radios and cognitive networks.

2. SOFTWARE-DEFINED RADIO AND COGNITIVE RADIO

A software-defined radio is a radio where many of the physical layer (PHY) functions and possibly the rest of the communications stack are implemented in software.

The term 'cognitive radio' extends beyond the traditional view of a physical radio frequency device capable or receiving and/or transmitting information over a wireless communications channel with some cognitive functionality. It is more useful to consider cognitive radio as a complete system, or a node in a network since cognitive functionality can have a direct impact on the entire communications stack and device control system. The physical layer of this cognitive radio may be implemented using a software-defined radio.

The three main elements of cognitive radio are the abilities to interpret data as knowledge, to make decisions according to a specific context and set of objectives and constraints and to develop new conclusions from these experiences for possible use in future scenarios. Cognitive functionality can be further described as a combination of multi-sensory and control functionality coupled into multi-dimensional optimization problems, where the parameters of the networks and nodes, the objectives, and the constraints may all have time-varying characteristics. The set of parameters can include all of the observable fixed and reconfigurable aspects of the networks and nodes. The objectives can include the user's information-conveyance requirements, and desired performance metrics, network objectives and communications channel-usage behavior. In addition, these objectives may have different levels of priorities, and timeframes in which, these objectives should be accomplished.

3. THE VALUE CHAIN

A value chain is a term used to describe the relationship between the revenue generated by a system, or the value derived by a system, and the costs associated with the development, deployment, maintenance and upgrade of the system itself. Cognitive radio offers the opportunity to modify the value of a communications network to a set of customers. It is possible therefore, to affect the potential revenue that can be derived from the use of this network by exploiting this ability.

According to Porter, a firm can create value through a series of activities to produce goods and services. These activities are embedded in a value system that eventually creates value for the ultimate customer. By carrying out the activities at a cost below the revenue generated, the firm makes profit. Value is created through specific direct activities such as operations, outbound logistics and service, and through indirect support activities such as procurement Human Resource Management (HRM) and technology development. Within the wider value system, value can be created through interconnections between firms, such as the integration of logistics information systems or joint production planning.

Value is typically measured in terms of revenue – the willingness of the ultimate customer to pay for value and this value can be a subjective viewpoint. Consumers may buy in bulk from a high-volume, low profit margin grocery store and view this as good value. Alternatively, some of these same customers may perceive higher-priced organic produce from a specialist store as also being good value. In addition, non-consuming customers measure value in other non-monetary ways. Regulators can limit the use of technology that is perceived to have a negative impact on society. Example of these include nuclear power, carbon dioxide emissions and cellular phone basestation masts. The provision of a school or playground near a new housing project can help to increase the perceived value of this area to people.

Within a value system, the value is defined either by a direct purchaser of the firm's goods and services (who is willing to pay a certain price for them) or by the ultimate consumer of the goods and services who places a monetary value on them. Much of the effort of supply chain or value chain management is devoted to identifying or predicting sources of customer value, and in maximizing that value at minimal cost.

One critical area of discussion revolves around the question of who is the ultimate customer? While this is often taken to be the consumer of the goods/services, there are other 'customers' in the system. A Food Standards Authority requires that regulations should be met for all food sold in a country, a Health and Safety Executive (HSE) demands that firms take account of employee and customer health and safety, and frequency spectrum regulators including the Commission for Communications Regulation (COMREG) in Ireland, imposes terms and conditions on telecoms operators. While it is difficult to quantify these societal values, in effect these bodies are attempting to define ,measure and manage these societal value sources. Hence when discussing value creation or migration, the involvement of multiple customers with different perceptions of value must also be considered.

4. VALUE CREATION AND MIGRATION

Value is not a static entity – it is unique to each customer and viewpoint, and is constantly evolving [2][3]. In fact, this is perhaps one of the appealing features of a cognitive radio-based system. As the cognitive system adapts to the local environment, scenarios and business models, a migration of value can occur 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. The vastly popular mobile phone Short Message Service (SMS) in Ireland and many other countries is one example of this. A facility which was provided as a minor addition by phone manufacturers became highly valued by customers. On the other hand, technology push such as the availability of video downloads is not generating the sales expected as customer do not assign significant value to the feature. It is the customer perception of value that is key, no value creation takes place until the customer adopts. For example, consider a cell phone with tri-band facilities, a 1000 item memory and a camera. This is of limited value to a customer who only wants to send SMS text messages to colleagues and call family members while within Ireland. However, the same phone may be of greater value to a businessperson traveling globally and needing to photograph product samples at various locations.

Likewise, in a more cognitive radio network sense, the ability to collaborate and combine resources with other cognitive radio devices may not be of high value to a user wishing to only send a file to a colleague, however the ability to exploit the 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 that may be affected by this disaster. Value migration is 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?
- When value changes (a change of target market and customer profile, for example) how to hold onto value?

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. This customer may not place a high value on the cognitive functionality itself (or even care), but if this functionality results in an universal 'one-touch' or 'no-touch' operation, requiring little conscious effort on their part, then a potentially valuable product can be realized. Likewise, dynamic spectrum access is of value to the average customer if this can ensure this 'always-connected' feature. 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.

Alternatively, from a consumer standpoint, extra value may be extracted from the use of cognitive functionality in radio systems by allowing a device to act as a message relay service when not in use by a user in return for a slice of the possible slice of the total payment (a micropayment) paid by the originator in return for the information transfer. This incentive could help the 'always-connected' value of a cognitive network by encouraging devices to act as nodes in an ad hoc network thus helping to reduce the

The potential of interference-free co-existence of different systems in the same spectrum segments using cognitive functionality may not necessarily be perceived as

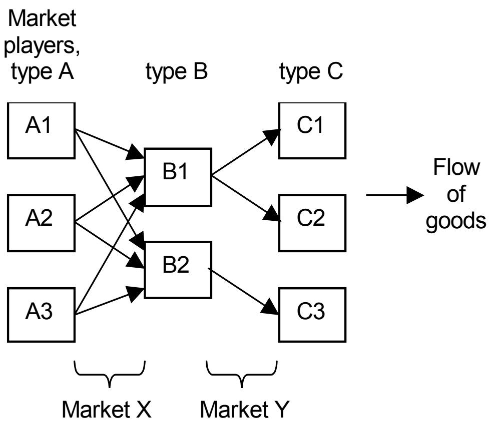

Fig. 1. Graphical representation of a three-stage supply chain.

a high-value feature from a consumer point of view. However, from a spectrum regulator 'value' viewpoint, this could shift some of the burden of regulation into the cognitive device and system space, enabling a move towards a self-regulation environment.

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, to the end user.

Fig. 1 is a graphical representation of a three-stage supply chain. In the context of this paper, **A** could be cellular network operators; B, Mobile Virtual Network Operators (MVNO); and **C**, End Users. Equally, **A** could be spectrum owners and **B** wireless access operators, etc. Many combinations are possible, but a viable value chain requires that all players in the chain are achieving a surplus in their respective transactions.

Fig. 1 is only a representation of the inter-relationships. A complete description of the value chain also requires descriptions of (a) the service or products delivered, (b) the market structure, and (c) the strategies followed by the players given that market structure. To decide the latter, companies will often build up business models to predict their performance. In this section, we do so for a network operator, while noting in the most general sense, a "network operator" could be as simple as a homeowner with a WLAN access point.

On 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 Eq. 1, where N_U is the number of subscribed users; $r_U(n)$ is the ARPU (Average Revenue Per User) in year n; c_I is the total CAPEX (Capital Expenditure) for network infrastructure; c_S is the price paid for the spectrum used; c_U is the average handset subsidy per user; and $o_I(n)$ is the OPEX (Operational Expenditure) for the network in year n.

While all of the above parameters depend on the interaction in the market place with other network operators,

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

Eq. 1.

suppliers and customers, the parameters N_U and $r_U(n)$ are explicitly related by the price demand curve, which in turn is heavily dependent on the market conditions.

Normalize Eq. 1 with respect to the number of users and consider the following set of fictitious figures: \$50 of CAPEX per user; \$10 of OPEX per user per year; average \$50 of handset subsidy per user; \$10 of spectrum licensing fees per user per year; and a discount rate of 0%. An ARPU greater than \$42 dollars per year would be required to bring the project into positive NPV within 5 years.

The above model allows one to make qualitative statements as regards the value-chain impact of SDR. These are given here in approximate order of decreasing potential impact:

- If new services and applications become technically feasible (peer-to-peer enterprise applications on ad-hoc networks) or significantly improved (e.g. reliable indoor coverage) then there is significant positive impact on the value: The number of users N_U and ARPU $r_U(n)$ increase. CAPEX and spectrum costs per user decrease.
- If SDR and CR is a critical enabler of dynamic spectrum markets, resulting in easy access to spectrum for a potential operator, then the barriers for entry for additional competition declines. Increased competition will generally reduce ARPU for well-established markets (e.g. cellular voice). In nascent markets, competition may promote increased network externality (i.e. increased utility to end users as the number of users in the network increases), increasing revenue as a result.
- The flexibility of CR and SDR may increase the lifetime of elements of the network, either reducing CAPEX c_I for upgrades or, in the best case, increasing the life of the system N_T.
- SDR handsets may be more expensive, especially where SDR is needed to enable new functionality (e.g. multi-standard roaming). This would be due to the increased complexity. However, this increase in expense in c_U (assuming the operator absorbs the cost) should be assessed in the context of the overall expense model.

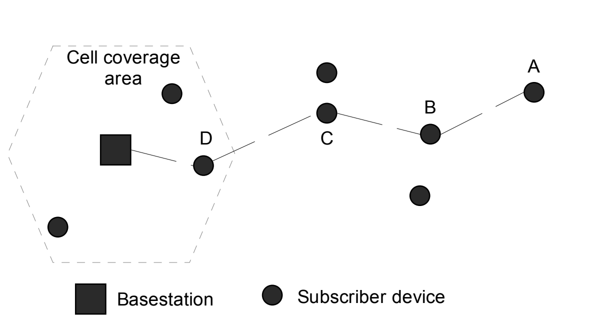

Fig. 2. Illustration of message-relaying for nodes out of basestation cell-coverage.

Thus, the large changes in the value chain are likely to occur where new services are enabled or the competition to provide existing services are changed. Other impacts such as increased handset cost or delayed CAPEX spend are less likely to significantly change the qualitative nature of the supply chain.

6. A NETWORK SCENARIO

This purpose of the following scenario is to help reinforce the concepts described in this paper. This basic scenario involves a communications network where technological change creates opportunities for new business models. Users can gain more value through increased communication coverage which will potentially increase the ARPU for the operator. In addition, users may have the potential to gain financial credit from the operator by contributing to the network infrastructure. Thus, value is increased and it migrates as the benefits are sheared between user and operator.

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, new planning regulations in an area deemed to have significant scenic value now prohibit the erection of new base-stations. The operator's main goal is to increase the revenue generated by the customers' increasing demand for voice, Short Message Service (SMS) and video call services in the region in addition 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 avoid further capital expenditure on network expansion.

Cognitive radio offers a solution to this problem, by enabling subscriber devices to become part of the network infrastructure themselves. Subscribers can upgrade to a new communications device with cognitive functionality,with a small initial investment. Extra value can be created by enabling the customer devices to act as message relays in the form of an ad hoc network but acting in an interference-free manner in the same licensed spectrum segments. This is illustrated in Fig. 2, where message traffic from **Node A** is relayed by **Nodes B** and **C** to **Node D**, which is within range of the basestation and can complete the wireless communications link.

Customers out of range of a base station but within range of another customer device can route their messages and voice calls through one or more available relays 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, $r_U(n)$, may be supported per year without having to significantly upgrade the network infrastructure thus helping to keep c_I at a static or slowly rising level thus increasing the ARPU.

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 an 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. Alternatively, the message-relaying service could act in parallel with the primary voice and SMS service.

We described earlier that value is a function of various economic variables, which can be expressed in the following way:

Value = f($c_I \;\; o_I(n) \;\; N_U \;\; r_U(n)$). Eq. 2

While in this scenario we would expect c_I to rise, it is also reasonable to expect N_U and $r_U(n)$ to rise. The business

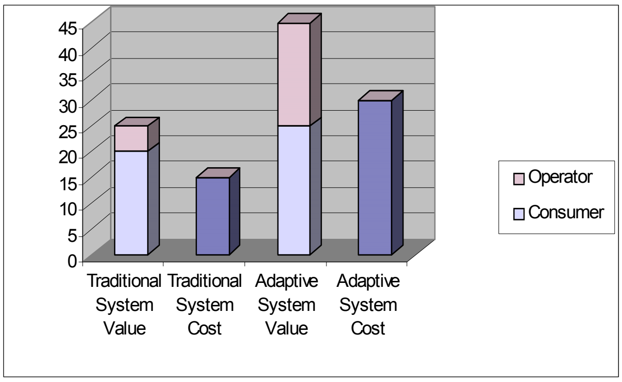

Fig. 3. Illustration of an increase in overall value.

case depends on whether NPV increases overall. Fig. 3 illustrates the difference in potential value derived a fixed-architecture system and a cognitive/adaptive system. In this example, the fixed-architecture system is incapable of change without having to replace the devices and/or physically upgrade the network architecture, whereas the operational objectives of the cognitive/adaptive system can change. It is feasible that the value derived from this system is potentially much greater than that of the fixed-architecture system, even taking slightly higher manufacturing and consumer costs into account. While that business case is yet to be proven, this scenario does illustrate how the principles of cognitive functionality have potential in terms of creating new value for users.

8. CONCLUSIONS

This paper introduced the concept of a telecommunications value-chain and explored two of the many ways in which the value-chain can be altered by 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 paper, a scenario involving cognitive radio technology operating in a customer-centric network was discussed in terms of the impact on the value-chain.

9. ACKNOWLEDGEMENTS

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