A Business Framework for Dynamic Spectrum Access in Cognitive Networks

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ABSTRACT

Traditionally, networking technology has been limited because of the networks inability to adapt resulting in sub-optimal performance. Limited in state, scope and response mechanisms, network elements consisting of nodes, protocol layers and policies have been unable to make intelligent decisions. Modern networks often operate in environments where network resources (e.g. node energy, link quality, bandwidth, etc.), application data (e.g. location of user) and user behaviors (e.g. user mobility and user request pattern) experience changes over time. These changes degrade the network performance and cause service interruption. In recent years, the words ***"cognitive"*** and ***"smart"*** have become the buzzwords and have been applied to many different networking and communication systems. Cognitive networks are being touted as the next generation network services which will perceive the current network conditions and dynamically adjust their parameters to achieve better productivity. Cognitive radios will provide the end-user intelligence needed for cognitive networks and provide dynamic spectrum access for better spectrum efficiency.

We are interested in assessing the practical impact of Cognitive Networks on the Wireless Communication industry. Our goal is to propose a formal business model that will help assess the implications of this new technology in the real world and the practical feasibility of its implementation.

We use the layered business model proposed by Ballon [8] which follows a multi-parameter approach by defining four levels on which business models operate and by identifying three critical design parameters on each layer. The Value Network layer identifies the important entities which come into the picture in the light of the new technology. The Functional layer addresses the issue of different architectural implementations of the Cognitive Networks. At the Financial layer, we propose a NPV model which highlights the cost/revenue implications of the technology in the real world and contrasts the different Dynamic Spectrum Access (DSA) schemes from a financial perspective. Finally, the Value Proposition layer seeks to explain the end-user flexibility and efficient spectrum management provided by the use of Cognitive radios and Cognitive networks.

Acknowledgments

"Why try to blend in when you are born to stand out. Fortune favors the brave"

My advisor Dr. Yaling Yang has been an immense help in guiding, directing and influencing my work. She has been a constant source of inspiration and has always supported me, even when I thought of working on an unconventional out-of-the-box topic. I also wish to thank Dr. Dilip Shome and Dr. George Morgan for their unconditional help and expertise to develop the financial model.

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Dedication

my grandparents
for inculcating in me strong cultural and social values

my parents
for making me believe in myself every step of the way

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1. <u>Introduction:</u>

Traditionally, networking technology has been limited because of the networks inability to adapt resulting in sub-optimal performance. Limited in state, scope and response mechanisms, network elements consisting of nodes, protocol layers and policies have been unable to make intelligent decisions. Conventional network structures have usually exhibited a hierarchical structure with centralized control. Communication of the network state information has been stifled by the layered protocol stack which prevents the elements of a network from being informed of the network status known to other elements.

The development of computer networks has seen a paradigm shift from the static, hierarchical network structures to highly distributed, autonomous systems without any form of centralized control. A modern network is a complex system composed of many heterogeneous nodes, links and users. A typical network schematic is shown below:

Modern networks often operate in environments where network resources (e.g. node energy, link quality, bandwidth, etc.), application data (e.g. location of user) and user behaviors (e.g. user mobility and user request pattern) experience changes over time. These changes degrade the network performance and cause service interruption. In order to maintain performance and service connectivity, networks must provide mechanisms to dynamically adjust to its surroundings. For networking nodes, the ability to self-adapt and self-organize in a challenging environment has become a key issue. Such adaptive mechanisms are implemented using four basic network functions: constructing hop-by-hop connectivity; routing data; scheduling data transmission and controlling transmission rate. A network adapts to changes by adjusting the behaviors of one or more of those network functions.

In recent years, the words ***"cognitive"*** and ***"smart"*** have become the buzzwords and have been applied to many different networking and communication systems. Cognition here is used in association with a technology that operates inside a complex environment, observes it, makes behavior choices and receives feedback from it all the while learning – assembling a data set that will help determine future behaviors based on past and current feedback.

Mitola [3], details a cognitive cycle as shown below in Fig 1.1:

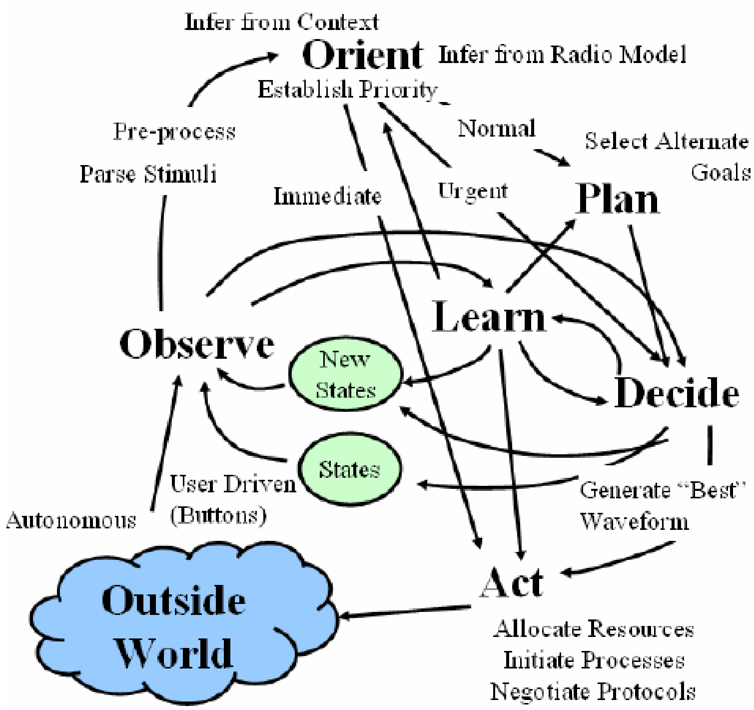
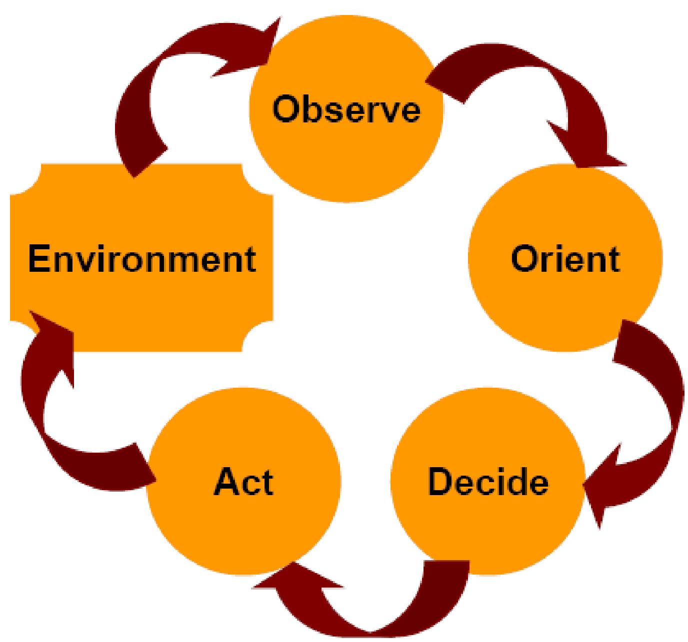


Fig 1.1 – Cognition Cycle (Mitola [3])

A simplified version of the same is presented by Thomas et al. [7] and is shown in Fig 1.2



A number of definitions of cognitive networks have been proposed.

Ramming [4] present a vision of cognitive networks in which the networks should be self-aware in the sense that they can make configuration decisions in the context of a mission and a specific environment. He argues that networks that manage themselves should require a new kind of technology known as cognate technology. He also contends that the network should be able to understand what the application is trying to accomplish and an application should be able to understand what a network is trying to do at any given moment.

Sifalakis et al. [5] define the term 'cognitive' when applied to networks to refer to the intended capacity of the network to adapt itself in response to conditions or events, based on reasoning and the prior knowledge that it has acquired.

Boscovic [6] defines a cognitive network as a network that can dynamically alter its topology and/or operational parameters to respond to the needs of a particular user while enforcing the operating and regulatory policies and optimizing overall network performance.

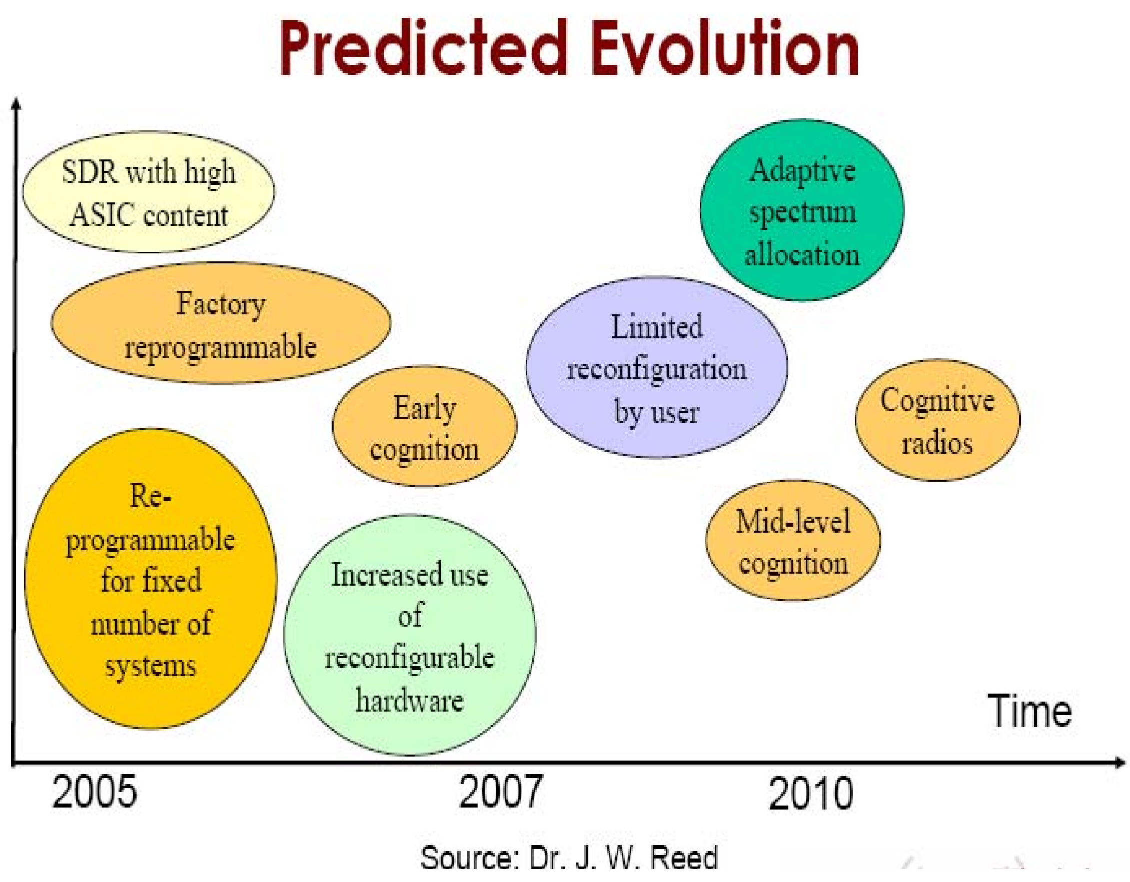
We use the definition provided by Thomas et al. [7]

"A cognitive network has a cognitive process that can perceive current network conditions, and then plan, decide and act on those conditions. The network can learn from these adaptations and use them to make future decisions, all taking into account end-to-end goals"

The fundamental model which forms a very important part for the cognitive network is the cognitive radio. Le, Rondeau et al. [8] define a cognitive radio as a transceiver that is adaptive, aware and capable of learning from experience. Thus the end-user intelligence required in a cognitive network is provided by such a radio. The radio knows its own capabilities, capable of sensing the RF environment and aware of the policies it needs to follow. On sensing the environment, the cognitive radio can adapt by tuning its parameters such as transmit power, modulation, waveforms, etc. Also the radio learns from its past experiences and uses the information gathered while making future decisions.

2. Problem Statement:

A lot of research is currently going on in the field of cognitive radios and their counterpart – cognitive networks. Specifically, Dr. Jeffrey Reed, one of the leading research experts in this field at Virginia Tech has predicted that cognitive radio systems may become commercially available as early as 2010. A predicted evolution time-line may be sketched with some certainty as shown in Fig 2.1:



We try to look at the business impact this technology will have on the wireless communication world. Specifically, we try to address the problem of the feasibility of the above technology in the real world.

One of the fundamental problems facing the wireless world is that of scarce spectrum. Most of the available spectrum has been allocated for various applications and services. However, the spectrum allocated to the primary license holders is not utilized completely. Cognitive radios address this problem through dynamic spectrum access. Akyildiz et al. [9] present a detailed description of how a cognitive radio achieves the temporal usage of the temporally unused spectrum called ***"spectrum hole"*** or ***"white space"***. If this band is further used by a licensed user, the cognitive radio either to a new spectrum hole or remains in the same band but modifies its transmit power or modulation to prevent interference with the licensed user. Such temporal usage is shown in Fig 2.2

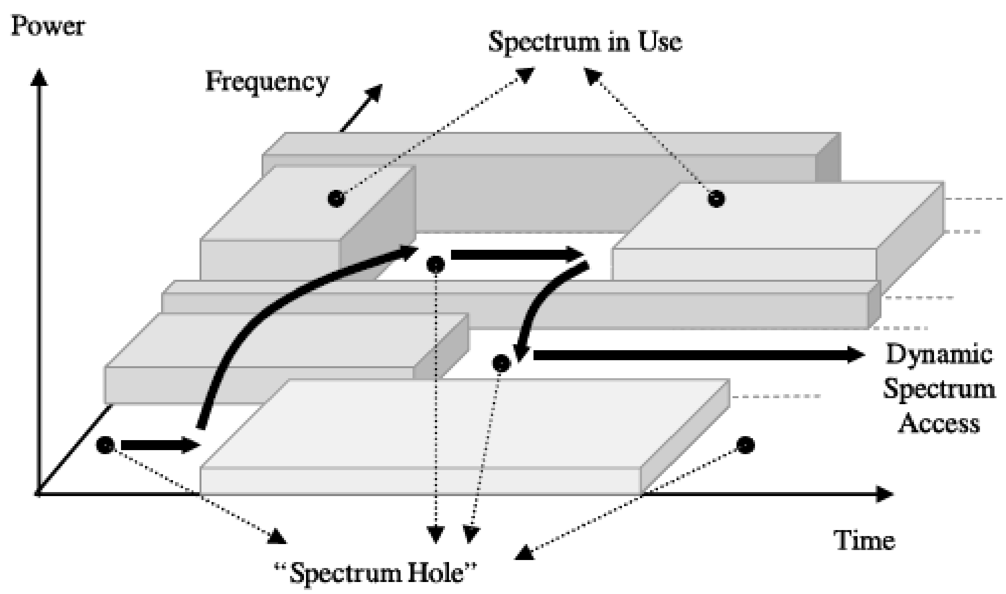


Fig 2.2 – Spectrum Hole Concept (Akyildiz et al. [9])

We try to evaluate the revenue impact of various types of spectrum access techniques. Using simulations, we try to find out which technique provides a utility function that maximizes the profit potential of the firm providing the secondary access services.

In sum, we attempt to answer the following questions –

- What will be the business model impact of Cognitive Networks on the wireless world?

- Is it practical and feasible for a firm to invest into this technology?

- How is the value created and distributed along the Wireless model value chain?

- What are the different functional models which a firm can consider while providing the technology?

- Which Dynamic Spectrum Access techniques will provide a utility function that maximizes the profits of the service providing firm?

- Will value be created for the end-user by the use of cognitive networks along with cognitive radios?

3. Business model: A Framework

Traditionally, a business model has been used to describe the external transactions of a company. These transactions include exchange of information, goods, services, money and knowledge.

In recent years, the definition of a business model has been developed and widened to include all the transactions that involve generation of revenue from sale of goods and services. Business models are being used not only to describe external transactions but also internal processes concerning production of goods and services.

Ballon et al. [1] define a business model as

"A model which tries to describe how a company or a set of companies intend to create value in the marketplace"

It is a means of structuring costs and revenue streams so that the business becomes viable. We try to propose a business model which will encompass both - the value creation process as well as the roles played by and the interaction between various entities in the process.

Types of business models:

Business models can be classified into various types [1] depending on their function, role, type, focus and range.

- Firstly, a distinction can be made based on whether the business model applies to a firm or group of firms or whether the business model applies to a specific product.

- Secondly, business models may either be oriented towards describing the roles played by various entities or may be geared towards a revenue model which makes estimates about future cash flows and profitability of a firm.

- Another distinction is between business model and business cases where-in the later is the application of the first

"Our model is technology specific; in the sense it applies to cognitive networks but is comprehensive since we not only provide an insight into the roles and interaction between various entities but also try to support the model through simulations run on a revenue model counterpart"

In economic literature, the following functions of a business model are mentioned

- To articulate value proposition to the end-user
- To identify the market segment which a particular technology will target
- To identify the value chain and analyze the distribution of value among different actors.
- To estimate cost structure and profit potential of the offering
- To describe the position of the firm within the value chain and identify its potential competitors and complementors
- To identify the corporate strategy that will give the innovating firms a strategic hold over its competitors.

Constructing a business model:

The first step towards constructing a business model is identifying the value chain. As soon as it has been identified, the next step should be determining the key entities which will play an important role in this chain. These entities are called as ***"actors"***. Actors in a value chain can be suppliers, producers, intermediaries or end-user. The actors interact with each other for exchange of goods and services. When these interactions are recurrent, a ***"relationship"*** or ***"linkages"*** are said to be created between them. It is this relationship or linkages that tend to structure the value chain. The relationships between various actors need not be power neutral. In most practically observed value chains, the assets are never distributed evenly. They are concentrated with some actors – the effect of which has become even more pronounced in these days since it affects a lot of parties involved in the process. As a result, a detailed study of hierarchies and power relationships is very vital in analyzing a business model.

4. The Value Chain

A value chain is a term used to describe the relationship between the revenue generated by the system and the costs associated with the development, deployment, maintenance and upgrade of the system. Value can be created through a number of direct and indirect activities. It is usually measured in terms of the revenues – amount which the end user is willing to pay for a particular good or service.

Value is not a static quantity. It gets created dynamically – sometimes intentionally and sometimes non-deliberately. Any activity which leads to an increase in value for the end-user is considered a ***"value-creating activity"***.

A topological schematic of a simple value-chain can is shown in Fig 4.1 below:

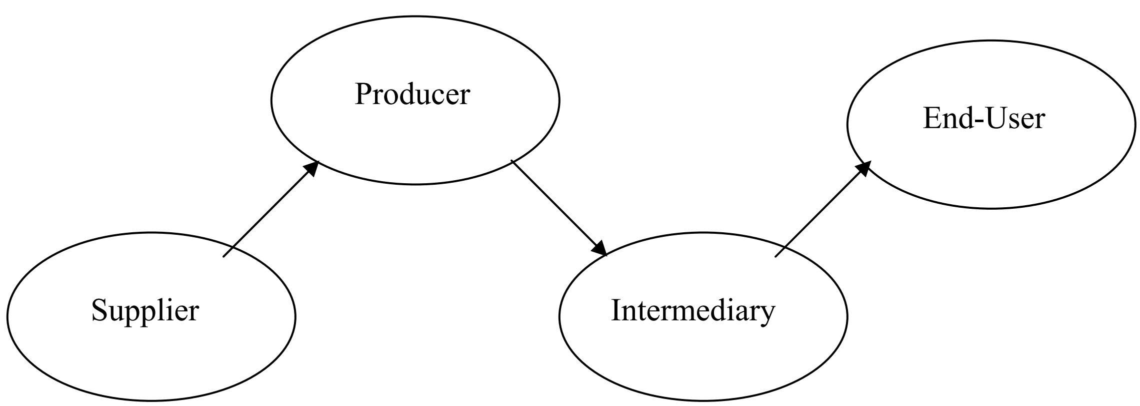


Fig 4.1 – Schematic of a generalized value chain

4.1) <u>Traditional Wireless Model: Value Chain</u>

A report by the Yankee Group [2] provides a basis for deconstructing the value network for wireless services.

The value network is shown below-

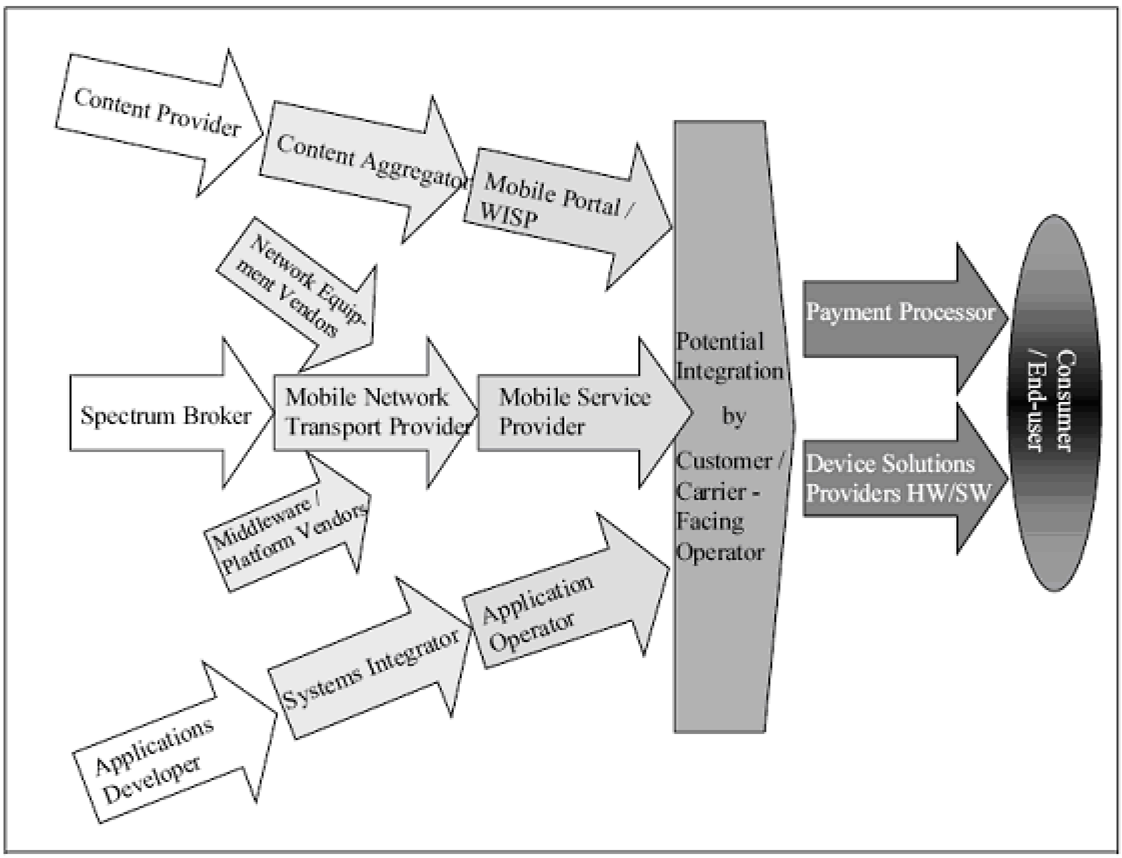


Fig 4.1.1 – Wireless Value System (Yankee Group [2])

This report describes the value chain as consisting of five major value chains

Network Transport:
This network operating value chain consists of spectrum brokerage, mobile network transport and mobile service provisioning. Network operators act as the gatekeepers, both in terms of customer ownership and in terms of limited resources such as spectrum and operating licenses.

Applications Operation:
The applications environment includes application developers, system integrators and applications operator. These companies are labeled wireless application service providers (WASP's)

Content Provisioning:
This value chain consists of content providers, content aggregators and portals. Portals also act as gateways to Internet and act as wireless Internet service providers (WISP's)

Payment Processing:
This includes the traditional billing relationship with the client.

Providing Device solutions:
Handset vendors form a very important part of the value system. They provide hardware as well as software solutions.

In addition to this there are two enabling value chains:

Network Equipment Provisioning:
This includes the companies which provide network equipment. Traditionally, infrastructure vendors provide a relatively standardized product.

Middleware / Platform Provisioning:
This includes companies which provide application platforms such as mobile portal platforms, mobile commerce platforms, WAP gateways, SMS gateways, etc.

5. Overview of the proposed model:

The business model we use is the one proposed by Ballon [8] which follows a multi-parameter approach by defining four levels on which business models operate and by identifying three critical design parameters on each layer. On the contrary to the traditional models, this model has a widened scope in the sense that it not only applies to a firm but rather encompasses the entire network of stakeholders, suppliers, distribution channels and intermediaries which take part in the production and delivery of the goods and services in question.

Ballon [8] gives a detailed description of the model. Below, we highlight some of the key points about the four layers and their design parameters –

Layer 1: Value Network Layer

At the value network layer we try to identify the key entities which play a part in the value chain. These entities are referred to as ***"actors"*** and the value adding activity which they provide in the market place is called as their ***"role"***. A role can have its own cost and revenue associated with it. A iterative interaction between various actors gives rise to a ***"relationship"*** between them. The most basic design parameters which are identified at this layer are:

- Combination of assets : The relative weights (hierarchies) between the actors
- Vertical Integration : The way in which roles are combined
- Customer Ownership : The relationships which exist between the producing actors and the consuming actors

Layer 2: Functional Architecture Layer

The technical system as a whole can be divided into a number of independent modules. This layer deals with the identification of specific modules, the interfaces between them, the distribution of intelligence within the system and its interoperability with other systems.

Layer 3: Financial Layer

This level is very important when it comes to actual implementation of the technology. It seeks to identify all the cash flows associated with the commercial use of the technology. It tries to project whether a technology will be profitable by predicting the revenues and costs that will be incurred over the life of the project. The alternate models available for consideration include:

- Cost (sharing) model
- Revenue model
- Revenue sharing model

Layer 4: Value Proposition Layer

This level tries to address the issue of identifying the value which is being created for the end-user and determine the composition of this value addition. We try to find a way in which to best position the given product in the market.

Table I Business model design parameters

Control parameters		*Value parameters*	
A. Value network parameters	*B. Functional architecture parameters*	*C. Financial model parameters*	*D. Value proposition parameters*
A1. Combination of assets	B1. Modularity	C1. Cost (sharing) model	D1. Positioning
A2. Vertical integration	B2. Distribution of intelligence	C2. Revenue model	D2. User involvement
A3. Customer ownership	B3. Interoperability	C3. Revenue sharing model	D3. Intended value

Table 5.1 – Business Model Layers and design parameters (Ballon [8])

5.1) Value Network Layer:

As discussed above, at this layer, we try to identify the actors, the roles they play and their relationships with each other.

For Cognitive networks and Dynamic Spectrum Access (DSA) techniques, the various actors can be summarized as follows:

1. Spectrum brokers:
   Two type of market makers need to be set up-

   a. Primary brokers: Responsible for distribution of new spectrum initially according to FCC specifications. The spectrum can be distributed using the auction approach in which the availability of spectrum for usage is initially advertised. Then the interested parties submit their tender offers. The highest bidding offer is awarded the spectrum for usage.

   b. Secondary brokers: Responsible for trading spectrum for secondary usage. These brokers can maintain a database (similar to a book maintained in financial markets) wherein the white spaces (spectrum) available at any point in time is recorded. The main function of these brokers will be to match the "ask" orders of the primary users with the "bid" orders of the secondary users. The "ask" price will be always higher than the "bid" price since the primary users will tend to benefit from the need of the secondary users. Also a servicing fee will be charged by the broker. This will constitute a bid-ask spread which acts as a premium paid by the secondary user for using additional spectrum. The operating licenses issued for usage of the secondary spectrum will be time-limited and will expire at maturity. This ensures that secondary usage exhausts at the allotted time.

2. Network transport provider:
   The network transport provider is responsible for the set-up and installation of the wireless network. The operation and maintenance of the network can be carried out either at the local level or by a centralized entity. The implications of these two alternate approaches will be observed at the functional and the financial model levels.

3. Network equipment provider / Middleware Vendors:
   They will be responsible for the distribution of initial hardware to the network transport provider for initial implementation of the network. They will be lower in the hierarchy to the Network Transport provider.

4. Application developers/ Integrators/ Operators:
   Responsible for development of applications useful for utilizing the network functionality as well as system operation and integration.

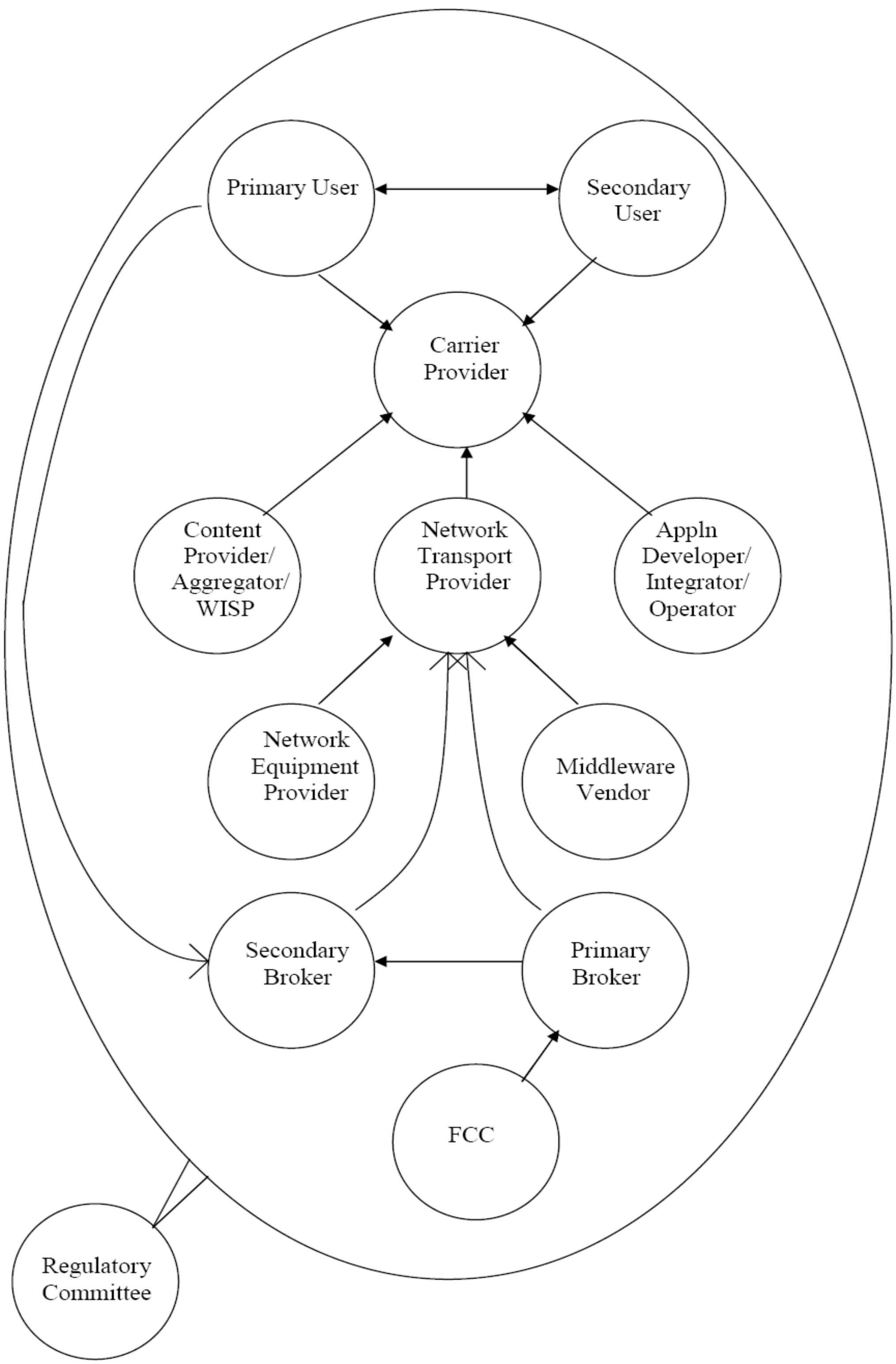
5. Content Providers/ Aggregators/ WISP:
   These entities include those providing data services (text, music, video, etc.) as well as advertising entities.

6. Carrier Provider:
   These are the customer-facing entities. They provide technical support as well as billing services to the end user.

7. End Users:
   End users can be of two types: Primary Users and Secondary Users. Primary users utilize the spectrum allocated initially in the primary markets. They can be military and defense organizations, large cellular service providers and even industrial manufacturers. The class of secondary users arises because of the cognitive characteristics. They may include organizations not needing spectrum usage on a regular basis or can be one of the primary users needing extra capacity during overloads or large bandwidth application requirements.

8. Regulatory authority:
   Due to the secondary usage of spectrum many problems may arise (*eg: failure to release spectrum after the allocated time, interference to primary users by the secondary users, etc*). A standard needs to be developed with regards to the transfer, usage and requirements for spectrum usage. The judicial body established must make sure that the charter is implemented and must have the authority to legally penalize the users who violate their contract.

Fig 5.1.1 below shows a hierarchical representation of the value network layer



Value Network parameters:

Combination of assets:
As previously discussed, this parameter is a measure of distribution of resources among the model as well as the mix of internal and external resources which a firm uses.

In our case, one of the important resource, spectrum, is highly concentrated with the brokers and FCC. On the other hand, the network transport providers use a mix of internal assets (network infrastructure) and external assets (middleware, network equipment) to provide the mobile transport services. Thus we find a mix of resource allocation, some highly concentrated and some evenly distributed.

Vertical Integration:
From the figure above, we clearly see a vertical integration relationship within various entities. The spectrum providers sit at the very top of the business chain. The spectrum provided by the primary and the secondary brokers is used in conjunction with the n/w equipment and middleware by the network transport provider to set-up and maintain the actual network.

Customer Relationship:
The carrier provider is ultimately the one which interacts with the end-user. They provide technical support and billing services. Also one of the important actors in this domain is the sales vendors which act as intermediaries and are responsible for attracting new users as well as provide hardware and software solutions to the customers.

5.2) Functional Architecture Layer:

At this layer, we address the issue of the different architectural models which can be used to set-up a cognitive network.

We define two types of architectures –

1. **Distributed Architecture**:

In this method, the end-user transceivers act as intelligent nodes. Each end-user radio scans the entire spectrum for available white spaces. As soon as a spectrum hole is identified, the secondary users start communicating on the unused frequency. Thus, in this architecture the intelligence is distributed throughout the system. An advantage of this approach is that it provides the end-user with added flexibility since he/she need not rely on the central controlling base station to provide secondary access. However, the complexity of the radios is very high in this model. As a result, implementing this type of architecture will be costly from the perspective of the end-user.

A lot of literature is available which proposes the implementation of a distributed system –

Zheng et. al. [19] propose a local bargaining approach where users affected by the mobility event self-organize into bargaining groups and adapt their spectrum assignment to approximate a new optimal assignment.

Huang et. al. [20] propose an Asynchronous Distributed Pricing (ADP) scheme where users exchange price signals that indicate negative effect of interference at the receivers. Given these set of prices, each transmitter chooses a channel and power level that maximizes its utility.

Ma et. al. [21] propose a Dynamic Open Spectrum Sharing (DOSS) protocol that allows nodes to adaptively select spectrum without relying on infrastructure.

Much more similar architectures have been proposed [22 – 25] for implementing distributed systems.

2. **Centralized Architecture**:

In this method, a centralized entity controls the spectrum allocation and access procedures. With aid to these procedures, generally, a distributed sensing procedure is proposed such that entities in the network forward their measurements about the spectrum allocation to the central entity and this entity constructs a spectrum allocation map.

Many solutions have been proposed for implementing a centralized architecture –

Brik. et. al. [26] propose DSAP: A Dynamic Spectrum Allocation protocol wherein the DSAP server determines an optimal distribution of radio spectrum among clients by maintaining a "*RadioMap*".

Raman et. al. [27] consider a centralized spectrum server that coordinates the transmissions of a group of links that share a common spectrum. By knowing the link gains in the network, the spectrum server finds an optimum schedule that maximizes the average sum rate subject to a minimum average rate constraint for each link.

On similar lines, Zekavat et. al. [28] propose a user-central wireless system configuration in which a user selects the optimum vendor to provide service at any time instance depending on various parameters such as vendor signal power, channel availability, congestion rate, cost per second and quality of service.

In our solution, we assume that the intelligence is concentrated in the base station which acts as the controlling entity. The end-user radios are dumb nodes which act as passive devices. We propose a "***distributed learning algorithm***" by which a base station learns about the channels on which the nearby nodes are communicating by using interference range estimates. Once the base station has this information, it can make the channel assignment to the new node accordingly. The advantage of this architecture is that spectrum sensing is not needed in end-nodes. As a result, the complexity of the radios is very less. In fact, conventional radios can be used for this architecture. As a result, this works out to be a cheaper solution from the user perspective.

	Advantages	Disadvantages
Distributed Architecture	High Flexibility	Costly
Centralized Architecture	Less Costly	Low Flexibility

Table 5.2.1 – Trade-Offs between the two architectural implementations

5.2.1) ***Distributed Learning Algorithm for Channel Estimation:***

Consider a node 'X' operating on an unknown channel 'x'. Suppose that this node is surrounded by many other nodes operating on a common channel, say 'channel 6'. The base station wants to determine the channel 'x' on which node 'X' is operating. All the nodes are dumb terminals. Each of the nodes surrounding 'X' tells the base station whether it is experiencing any interference. Consider the nodes that experience interference and are farthest from the node 'X'. By geometry, the node X will lie at the center of the area formed by these interfering nodes. The radius of this area gives us the interference range 'I' of channel 'x' with respect to channel 6. The base station can then compare this interference range to its database to determine the possible set of 2 channels which channel 'x' belongs to.

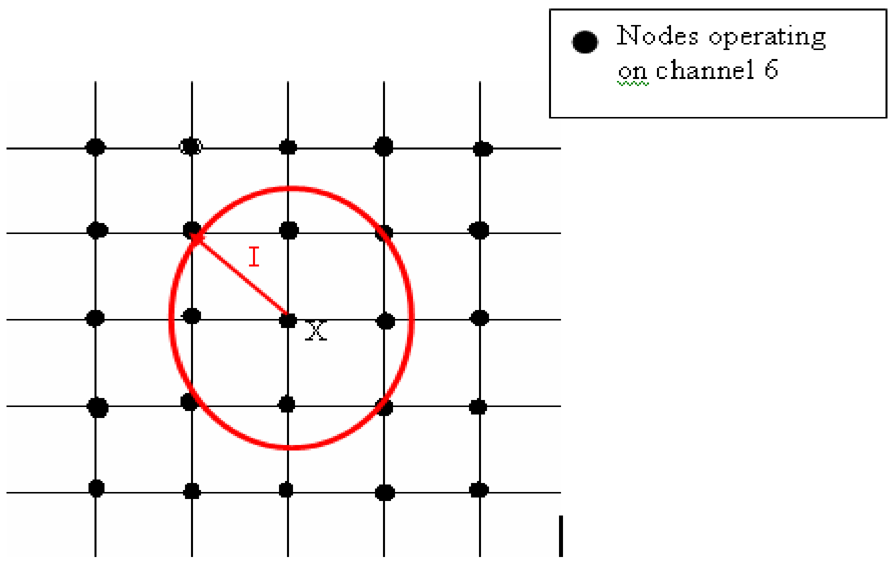


Fig 5.2.1 – DLA: Single Channel Scenario

If the base station knows the interference range estimates for each channel difference combinations, then using the value of I, we can narrow our search for 'x' to one of the possible two channels equidistant from channel 6.

Now, consider a scenario in which the nodes surrounding the node ‘X’ are operating on different channels. As the difference between the channels on which the two nodes are communicating increases, the interference range between them reduces. Let [Y_i] denote the set of nodes operating on channel ‘i’. Each set [Y_i] will narrow down the search for channel ‘x’ to two equidistant channels from channel ‘i’ as discussed above.

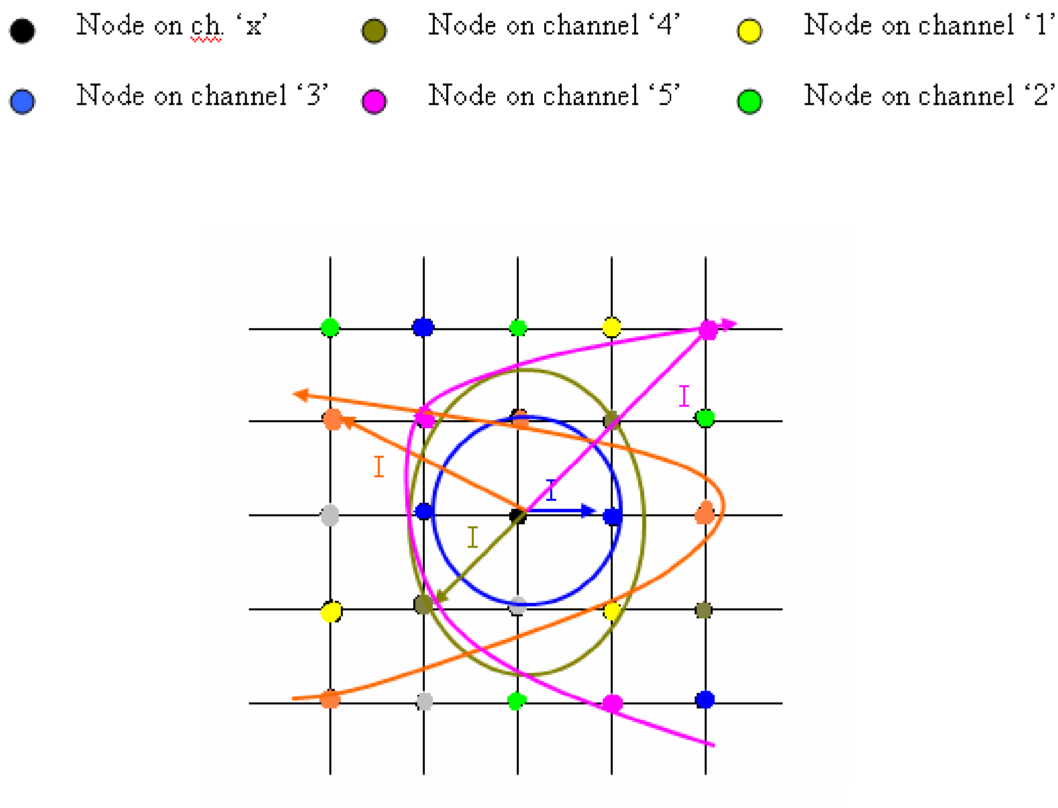


Fig. 5.2.2 – DLA: Multiple Channel Scenario

Each interference range estimate ‘I_i’ will narrow down the search of channel ‘x’ to two equidistant channels from corresponding channel ‘i’. With sufficient number of estimates, the base station can then use the intersection of these observations to determine the channel ‘x’ accurately. To make our observations independent of the transmit power, we compare the ratio of two interference ranges with the database maintained at the base station rather than the interference ranges themselves.

Algorithm:

1. *Determine the interference ranges for different channel combinations. Construct a database table in the base station which stores the value of interference range 'd_j' for each value of channel difference 'j'.*

2. *For j,k = 1 to n - 1 (n - no. of channels),*
   Calculate (d_j / d_k) for all $j \neq k$
   Store each ratio in the database.

3. *Let 'x' be the node whose current communication channel 'y' is to be determined.*

4. *Let [C_i] denote the set of nodes communicating on channel 'i' surrounding 'x'.*

5. *Each node tells the base station whether it is experiencing any interference or not.*

6. *Let [S_i] denote the set of nodes which experience interference because of 'x'.*

7. *By geometry, 'x' lies at the centre of the area formed by the set S_i. We can deduce the distance '$D_{i,y}$' for each channel 'i'.*

8. *For $i \neq p$, Calculate $D_{i,y} / D_{p,y}$.*

9. *Compare with the ratio value in the table.*

10. *We know 'i' and 'p'. For the closest ratio match, we can calculate the difference between both 'y – i' and 'y – p'.*

11. *Thus, we can determine 'y'*

12. *Go back to step 3 for other nodes.*

In the above algorithm, we take the ratio of interference ranges to make our comparison independent of transmission power. Also we have made a basic assumption that only a single node is transmitting on channel 'y'. If this assumption is relaxed, then advanced pattern recognition techniques can be further used to identify the channel assignments. Once a base station has all the information regarding the channels in use, it can then allocate the free spectrum in its vicinity to the secondary users for time-limited transmissions.

Implementation of the Distributed Learning Algorithm:

In order to get estimates of interference ranges and hence their ratios, we set-up a wireless test-bed consisting of 5 nodes. Each node used a Fedora – 6 operating system and was equipped with a TrendNet card capable of operating in 802.11 wireless modes.

Appendix 1 details the code we developed for taking throughput measurements. Our aim is to obtain the interference range for different combinations of channel on the two communicating links.

1. Suppose that the two pairs of nodes are communicating on channels 'i' and 'j' respectively.

2. Initially both the pairs of communicating nodes are kept far apart from each other so that no interference is seen at the respective receivers. Our code keeps a track of the number of packets received each second.

3. Then slowly the distance between the pair of communicating links is decreased till the point where the throughput at either or both the receivers drops.

4. This distance 'd_k' is the interference range that corresponds to channel difference $k = |i - j|$.

5. The above steps are repeated for different combinations of channel 'i' and 'j'.

6. The above procedure was repeated several times to weed out the incorrect measurements and then the average interference range was determined for each channel difference combination.

7. Once 'd_k' is calculated for each channel difference 'k', their ratios can be obtained and further used to implement the distributed learning algorithm.

Table 5.2.2 illustrates our results for average interference measurements for different channel combinations whereas Table 5.2.3 details our final results.

Channel Combination	Interference range (meters)	Channel Combination	Interference range (meters)
1 – 1	13.26	6 – 6	12.89
1 – 2	8.08	6 – 7	9.21
1 – 3	7.59	6 – 8	6.98
1 – 4	4.69	6 – 9	5.15
1 – 5	3.21	6 – 10	3.84
1 – 6	0	6 – 11	0

Table 5.2.2 – Average interference range measurements for different channel combinations

Channel Difference	Interference range (meters)
0	13.075
1	8.645
2	7.285
3	4.92
4	3.525
5	0

Table 5.2.3 – Interference ranges for different channel differences

5.3 The Financial Layer

The primary user will invest in the proposed Cognitive Network technology only if the value of the investment exceeds the value of its costs. i.e. if the investment has a positive net present value (NPV > 0)

In section 5.3.1, we develop the conceptual framework for implementing the NPV decision criterion. Section 5.3.2 revisits the network technology choices that the primary user can provide & that derive the revenue and cost streams, essential inputs to the NPV analysis. Section 5.3.3 presents a quantification of the NPV model. Finally, Section 5.3.4 provides a brief introduction to the Real Options framework for project evaluation. This offers an augmentation of the NPV analysis that incorporates future opportunities that could be available by virtue of having made the investments.

5.3.1 NPV Analysis: a conceptual framework

Definition of value: The value of any asset is the present value of expected future cash flows discounted at the investor's required rate of return.

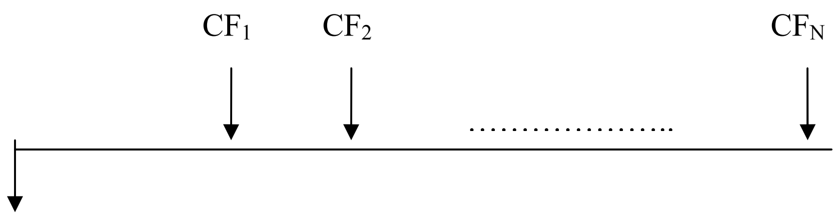
Calculating Present Values

The present value of a single payment received in year n:

$$PV = PV(CF_N) = \frac{CF_N}{(1+r)^N}$$

where, 'r' is the appropriate discount rate commensurate with the risk of the cash flows.

The present value of a cash flow stream is therefore the sum of individual cash flows:



$$PV = PV(CF_1) + PV(CF_2) + \ldots\ldots + PV(CF_N)$$

Determinants of the investor's required rate of return

When an investor buys the financial claims on a firm, i.e, lends money to the firm, he or she requires a rate of return to compensate for

(i) giving up current consumption for future consumption

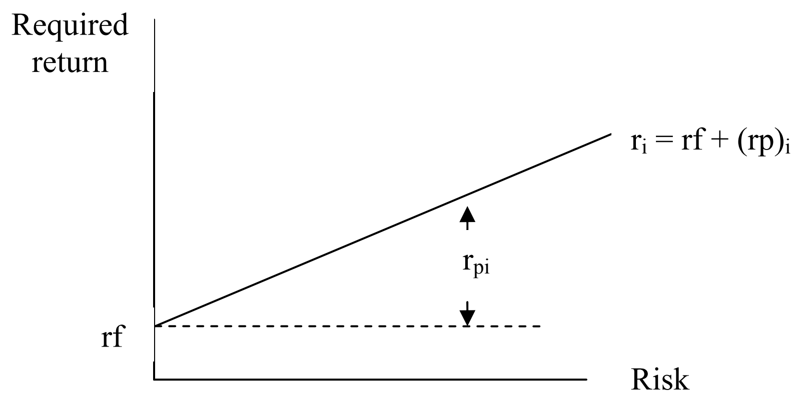
(ii) giving up certain consumption for uncertain consumption

Therefore, for an asset i, the required rate is

$r_i = r_f + (rp)_i$

where , r_f = risk-free rate: compensation for time value of money
rp = risk premium: compensation for risk

<u>Basic tenet of finance</u>: higher the risk, higher the required risk premium rp_i and higher the required rate r_i



Estimation of the investor's required rate of return

Motivation: the investor's required rate of return is the firm's cost of capital which in turn forms a basic input of the firm's capital investment decision

Capital Asset Pricing Model (CAPM) estimation of the required/expected rate of return

CAPM quantifies the relationship $r_i = r_f + (rp)_i$ as:

$$r_i = r_f + \beta_i\,(r_m - r_f)$$

where,

r_i = risk free rate, the return on a government security

$(rp)_i = \beta_i\,(r_m - r_f)$= risk premium for asset i, based on the relevant risk of asset

β_i = beta coefficient = relevant risk of asset i

$(r_m - r_f)$ = market risk premium

Definition of NPV:

The value of a project is the present value of expected future cash flows discounted at the projects' risk adjusted required rate of return.

$V = PV(CF_1, CF_2, \ldots\ldots, CF_N) + PV(TV_N)$

Future cash flows include cash flows projected over the estimation horizon (CF_t , t = 1 to N) and a Terminal Value (TV_N) which is the present value of all cash flows beyond the estimation horizon.

Let I = Initial investment
V = Value of the project as calculated above

Then, NPV = V – I

Selection criterion:

A project is accepted if NPV > 0

& rejected if NPV < 0

Implementation of the NPV criterion:

To implement the NPV method we need to define and measure the discount rate and the cash flows.

Discount rate measurement:

Since the project is financed by an (optimal) mix of debt and equity capital, the discount rate (or the investor's required rate on the capital mix) is measured as the after-tax weighted average cost of capital (wacc)

$$wacc = w_d k_d(1\text{-}t) + w_s k_s$$

where,

k_d = cost of debt = $r_f + \beta_d (r_m - r_f)$ in the CAPM framework

$k_d(1 - t)$ = after tax cost of debt, since interest on debt is tax deductible

k_s = cost of equity = $r_f + \beta_s (r_m - r_f)$ in the CAPM framework

w_d and w_s = proportion of debt and equity in the firm's capital structure.

Annual cash flow measurements:

The annual cash flows (Free cash flows = FCF) are estimated as

FCF_t = [EBIT(1-t) + Depreciation – Capital Expenditure – ΔNWC]$_t$

= Operating income after tax + Cash flow adjustments

where, EBIT = Operating income = (Revenues – Operating costs & Expenses)

The cash flow does not include the tax benefit of debt financing i.e, the interest tax shield, because it is included in the discount rate, in the after tax cost of debt.

Terminal Value, (TV_N):

The terminal value for an on-going firm or project is the present value of cash flows beyond the estimation horizon, 1 to N, over which the cash flows are projected in the valuation analysis.

Note:

(i) The terminal value is most commonly estimated as a growing perpetuity assuming that the cash flow, CF_N, in the last year N will continue to grow at a constant rate, g. Thus,

$$TV_N = \frac{CF_N(1+g)}{wacc - g}$$

where, k = wacc is a discount rate commensurate with the risk of the cash flows.

(ii) If the cash flow after year N are assumed to be a level perpetuity (g=0), Then,

$$TV_N = CF_N / wacc$$

Value of the project, V = PV(annual CF_s) + PV(terminal value)

= PV(CF_1, CF_2, ……, CF_N) + PV(TV_N)

Net Present Value of the project = NPV = V – I

5.3.2 Technology choices and the Revenue function

The implementation of the NPV criterion requires the estimation of future cash flows and costs – both operating costs and capital expenditures. The primary user's cash flows and costs will depend on the particular Cognitive Networking technology offered to the secondary user. In this section, we revisit the alternative technology choices available to the primary user.

Dynamic Spectrum Access – 1 (DSA 1)

In this method, the secondary user is allowed to transmit simultaneously with the primary user. However, since simultaneous transmissions can lead to interference, it is necessary in this method to put some constraints on the secondary user transmission. First and foremost, the transmission power of the secondary user should be maintained below a threshold such that there is no distortion of the primary user's signal. As a result, the network of the secondary user is essentially a short range one. Hence this scheme will have limited utility from the perspective of the secondary user. Secondly, the modulation techniques which can be used by the secondary user also need to be pre-approved by the primary user, in a way that the secondary transmission doesn't cause interference with the primary user transmission. An advantage of this type of spectrum access is that the secondary transmission need not be time-limited, even if the primary user may still prefer it to be so.

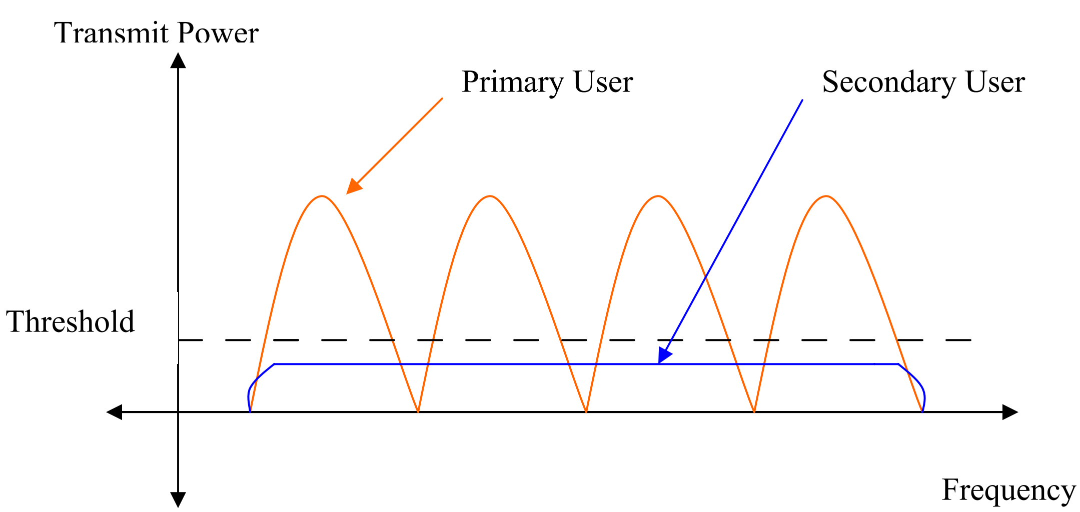


Fig 5.3.1 – DSA 1

Currently, most of the wireless communications of this type tend to take place in the 2.4 GHz and the 5 GHz spectrum range since this spectrum has been made available free of charge to the public. However cognitive systems try to achieve efficiency in spectrum utilization by dynamically switching channels to make use of white spaces available in the spectrum owned by the primary user. While doing so, the secondary user must pay for the spectrum usage in other frequency bands which are not available free of charge.

In case of DSA 1, the spectrum usage price charged by the primary user will depend on the demand and supply curves. However, we may argue that since the spectrum access and the consequent transmission does not interfere with the primary transmission, this type of transmission may be provided essentially cost-free for the secondary user in all the frequency bands. (i.e spectrum usage charge = 0). In this case, the revenue generated by the primary user may be primarily because of the sale of equipment (eg: wireless earphone, keyboards, etc.) The system costs for the secondary user are high in this scheme. However once the upfront investment is made, the consequent use may be essentially cost-free.

Dynamic Spectrum Access – 2 (DSA 2)

In this method, the primary user gives a time-delimited license to the secondary user to utilize spectrum which he/she is not currently utilizing. Usually these types of contracts are long-term. The primary user determines on an average the amount of spectrum necessary during the day. This average usage is calculated such that it can enable primary user transmission even during the peak load conditions in the network. They then enter into a contract to lease the remaining spectrum they possess to the secondary user, usually as a long-term arrangement. Such spectrum access thus falls in the co-operative type.

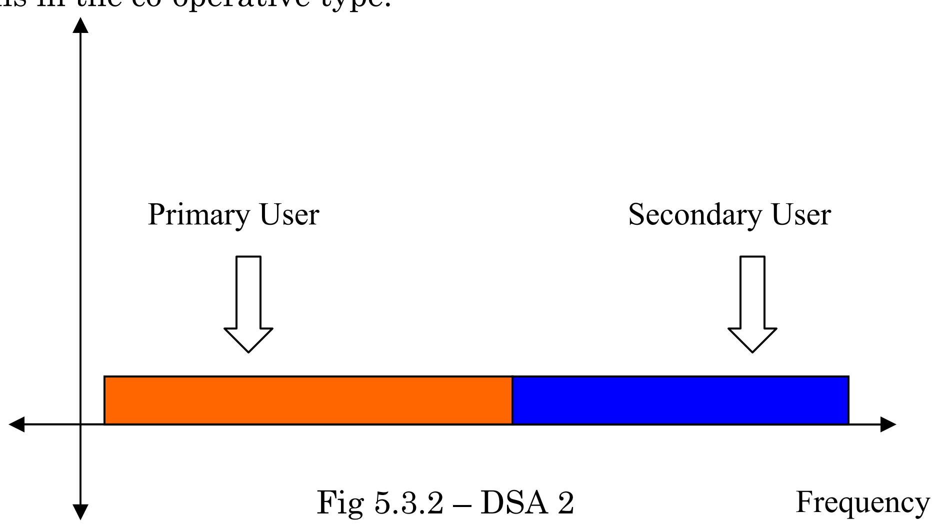


Fig 5.3.2 – DSA 2

As long as a guard channel is maintained between the transmission of the primary and secondary users, there need not be additional constraints imposed on the secondary user. The primary user will charge a higher spectrum usage price (P_Y) since the secondary user has access to the entire leased spectrum and is free to choose the transmission power and modulation technique as long as his/her signal does not spill over into the primary user spectrum. On the other hand, no new modifications need to be done to the secondary user system.

<u>Dynamic Spectrum Access – 3 (DSA 3)</u>

This type of spectrum usage is feasible when the primary user transmission occurs non-continuously in bursts. In this method, the secondary user radio senses the spectrum before it transmits. If the spectrum is not being utilized by the primary user then the secondary transmission takes place. If the secondary user detects a primary user in transmission, it will back-off and try later after some time.

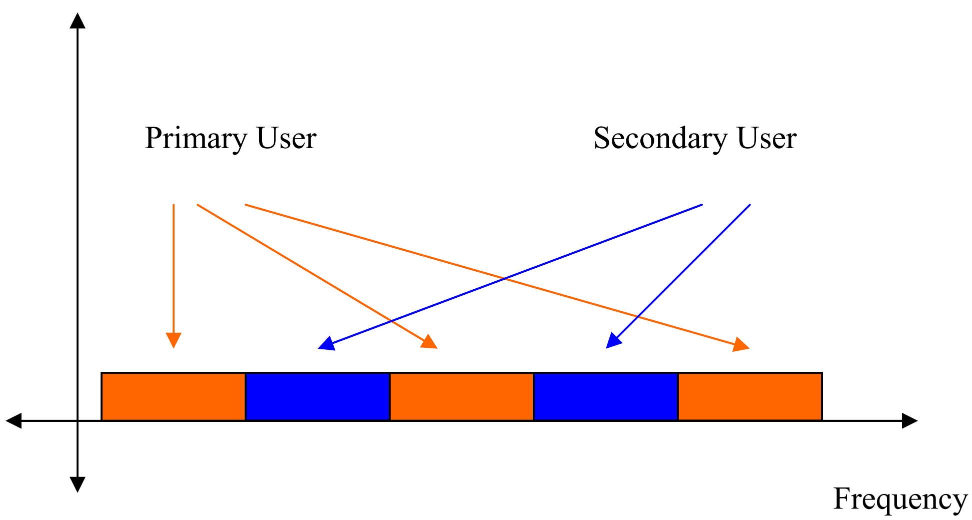


Fig 5.3.3 – DSA 3

The spectrum usage price (P_Z) charged by the primary user could be lower than P_Y charged in DSA 2 because of the additional transmission constraints. However, the secondary user will need to invest a lot more in his communication system since precise sensing and accurate decoding is necessary in the transceivers.

The Revenue Function

The pricing of the spectrum depends on population density, coverage area, topography, amount of spectrum assigned, licensing parameters and opportunity costs of the leased spectrum. We try to model most of these parameters in the following analysis.

Since we are interested in the NPV of the incremental investment, the only revenues and CF's that are relevant to the analysis are those that are contingent on making the incremental investment. Since the potential revenues from DSA 1 are independent of the network investment required for DSA 2 and DSA 3 and are independent of the use of DSA 2 and DSA 3 by the secondary users, the revenue function related to the incremental investment does not include DSA 1. Revenues from DSA 1 are best viewed as incremental revenues from the existing investment impacting existing revenue growth which we capture in the simulation analysis. In modeling the primary user's investment decision we assume that the primary user provides both DSA 2 and DSA 3.

Let $Z_{as}(i)$ be the spectrum bandwidth assigned to the primary user for a period 'i'.

Let $Z(i) < Z_{as}(i)$ be the spectrum bandwidth actually used by the primary user communicating using DSA – 2 for time Δt_2.

Let Z'(i) be the total amount of spectrum bandwidth used for time Δt_3 when the primary user transmits data in bursts using DSA – 3.

Then, we can say that

$$Z(i) = z_0 \cdot v(i) \cdot f = \frac{z_0 \cdot f}{s} N(i)$$ ………………(Eq. 5.3.1)

where,

- z_o – carrier bandwidth per carrier
- v(i) – number of carriers
- f – frequency reuse parameter
- s – number of channels per carrier

N(i) = v(i).s is the number of channels at a particular cell.

Let ΔR_t be the incremental revenues which a primary user receives because of the implementation of the interpreted technology over the traditional revenues R_0.

$$\Delta R_t = [Z_{as}(i) - Z(i)].\ \Delta t_2.P_Y + [Z_{as}(i) - Z(i) - Z'(i)].\sum \Delta t_3\ .P_Z - \text{Cannibalization of } R_0$$

……………… (Eq. 5.3.2)

where,

- Δt_2 – time for which the spectrum is leased to the secondary user
- Δt_3 – time for which the spectrum is leased to the secondary user in time slot 'i'
- P_Y – spectrum price charged per unit time by the primary user for 1 MHz of spectrum usage under DSA 2. ($ / MHz-sec)
- P_Z – spectrum price charged per unit time by the primary user for 1 MHz of spectrum usage in DSA 3. ($ / MHz-sec)
- $Z(i)$ – spectrum used by the primary user as detailed in eq. 5.3.1

As we have seen above, there are two different schemes in which the primary user can offer secondary access to the additional unused spectrum.

The spectrum usage fees charged by the primary user will follow the fundamental laws of demand and supply. The demand from the secondary users will depend on their perception of the costs and benefits which vary across DSA 2 and DSA 3 as described earlier. This in turn will establish P_Y and P_Z.

Fig 5.3.4 illustrates the supply and the demand curve. The point at which they intersect is called the equilibrium point for that market. Each price corresponding to this point is the price (P_Y and P_Z for each DSA method) that the primary user expects to earn by leasing the spectrum.

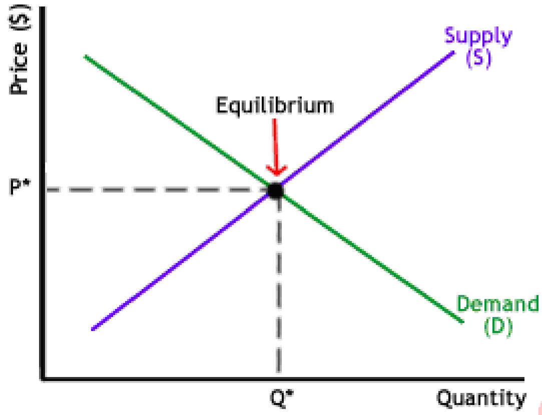


Fig 5.3.4 – Law of Demand and Supply – Source: Investopedia [17]

Now, if at a given point there is excess availability of the spectrum and less number of secondary users (demand < supply), the spectrum price must fall to clear the market. As a result the technology becomes more appealing to the purchasers. Hence the number of secondary users increases and so does the demand. This progresses until the equilibrium point is once again achieved. Vice versa, if the number of secondary users is more than the availability of the spectrum (demand>supply), the opportunity cost of using the additional spectrum increases (under the assumption that some of these secondary users are willing to pay more). That is, the spectrum price increases. So, the demand reduces at this increased price. So, once again the equilibrium is set-up. Fig 5.3.5 illustrates the cases of excess supply and excess demand respectively.

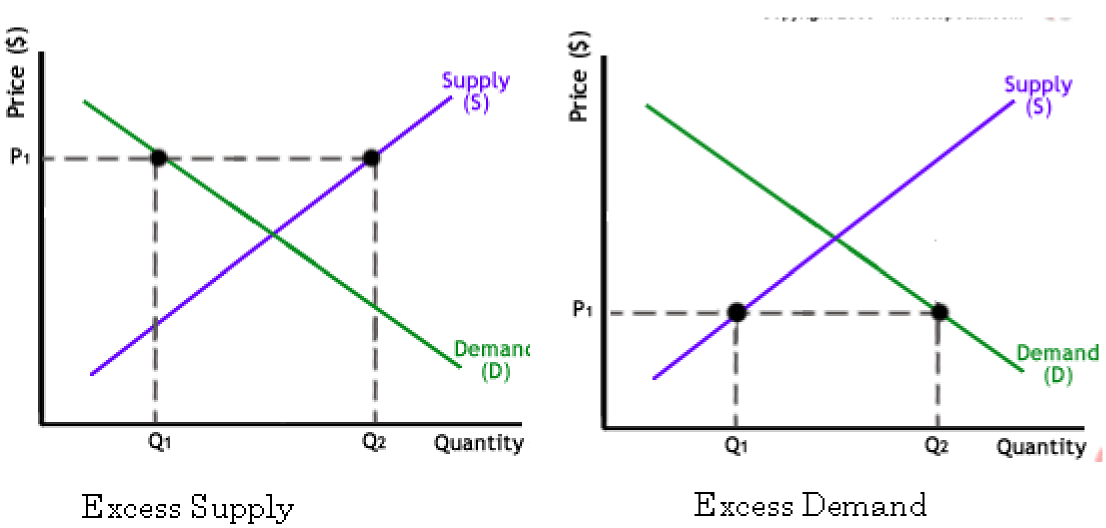


Fig 5.3.5 – Cases of Excessive supply and demand – Source: Investopedia [17]

5.3.3 – Quantification of the NPV model:

As we have established earlier

- $NPV = PV(CF_1, CF_2, \ldots\ldots, CF_t) + PV(TV_N) - I$

  The present values of the annual cash flows (CF_1, CF_2, ……, CF_t) and the terminal value (TV_N) are obtained by discounting them at the firm's weighted average cost of capital.

  $wacc = w_d.k_d.(1 - t) + w_s.k_s$

- ΔCF_t = annual cash flow

  $= EBIT(1 - \text{tax rate})_t + (Dep)_t - (CapEx)_t - \Delta NWC_t$

  Given the paucity of data, we make the following not unreasonable assumptions:

  (i) The annual, on-going capital expenditures, $(CapEx)_t$ are incurred to just offset the annual depreciation $(Dep)_t$. i.e. $(CapEx)_t = (Dep)_t$.

  (ii) The working capital needed to support the revenue growth is flat. i.e. $\Delta NWC_t = 0$.

  Thus,

  $\Delta CF_t = EBIT(1 - \text{tax rate})$

  $= (\text{Revenue} - \text{Operating Costs \& Expenses})(1 - \text{tax rate})$

  $= (R - \text{Operating Costs \& Expenses})_t\,(1 - \text{tax rate})$

- $TV_N = CF_N (1 + g) / (wacc - g)$ ……(assuming that CF's after year N grow at a constant rate = g)

  $= CF_N / wacc$ ……(assuming terminal growth rate, g = 0)

- I = Initial capital outlay, including R&D costs

Depending on the data availability, the following analyses are possible:

Case 1 – If all the inputs to the model can be estimated with reasonable confidence, the NPV of the investment can be estimated which precisely measures the value created by the investment.

Case 2 – If only the cash flows can be estimated with any degree of precision, the model can be implemented to deduce the upper limit on the investment outlay (I*) to ensure NPV > 0,
i.e. $I^* < PV(CF_1, CF_2, \ldots\ldots, CF_t) + PV(TV_N)$

Case 3 – If only the R&D costs and capital investment needed can be estimated, the model can establish the lower bound on the present value of CF's (CF*) to ensure NPV > 0,
i.e. $PV(CF_1^*, CF_2^*, \ldots\ldots, CF_t^*) + PV(TV_N) > I$

Since Cognitive Systems are in the early stage of development, quantifying the R&D costs and investment required is infeasible. However, there is historical data available on the revenues and operating costs in the wireless telecommunication industry which can be used to approximate the cash flows of the primary user. Accordingly, we focus on Case - 2 and attempt to establish an upper bound on the investment in the technology. Given the uncertainty in the inputs to the model, our strategy is to simulate a distribution of the upper bound on the investment by assuming distributions for the cash flow components and the discount rate.

Estimation of the discount rate, wacc:

wacc = after tax weighted average cost of capital

$= w_d.k_d.(1 - t) + w_s.k_s$

- Cost of Debt: Using the CAPM, $k_d = r_f + \beta_d (r_m - r_f)$

  where,

  r_f = currently prevailing risk-free rate, measured as yield on long term treasury bonds [12]

  $r_m - r_f$ = Market Risk premium
  = 6.5% from Ibbotson & Sinquefield [14]

  β_d = bond beta = 0.1 in the base case

  Note: Beta coefficients are measured as the slope of regression of asset returns against the market returns. Since the market prices, hence return data on the infrequently traded bonds are not readily available; practitioners use range of values 0 – 0.25 based on empirical evidence.

  $k_d = r_f + \beta_d (r_m - r_f) = 4.5 + 0.1(6.5) =$ **5.15%**

- Cost of equity: $k_s = r_f + \beta_s^* (r_m - r_f)$

  As determined above:

  $r_f = 4.5$ %,

  $(r_m - r_f) = 6.5$ %

  Note: Equity beta (β_s) : We estimate the equity beta as the average beta of comparable publicly traded firms. Since stock prices and return data are readily available for public firms, equity betas are calculated using regressions of stock returns against market returns and are available in published form. Our comparable set of firms is Verizon, AT&T and Sprint.

Verizon	0.95
AT&T	1
Sprint	1.1
Average	1.02

Table 5.3.1 – Average beta measurements for comparable firms
Source: Value Line Investment Research [11]

Thus, $k_s = r_f + \beta_s^* (r_m - r_f) = 0.045 + 1.02(0.065) =$ **11.13%**

- w_d, w_s : proportion of debt and equity in the firm's target capital structure.

  We estimate the primary user's target capital structure as the historical average capital structure of the three comparable firms [12] (See table 5.3.3, 5.3.4 and 5.3.5)

	$w_d = D/V$	$w_s = S/V$
Verizon	0.22	0.78
AT&T	0.15	0.85
Sprint	0.17	0.83
Average	0.18	0.82

Table 5.3.2 – Capital Structure for comparable firms

- Tax rate, t = 35% (assumed)

- **wacc**: Thus, the base case value of the discount rate is

  wacc $= w_d.k_d.(1 - t) + w_s.k_s$

  $= 0.18(0.0515)(1 - 0.35) + 0.82(0.1113)$

  $= 9.73\% \sim$ **10%**

Verizon Wireless (VZ)						
Year	LT Debt	Current Liab	Yr. End Cl	Shares Out	Market Value of Equity	D/V
1995	6407.2	1930.2	66.875	437.702	29271321250	0.179581
1996	5960.2	2137.3	64.75	437.762	28345089500	0.17374
1997	13265.2	6342.8	91	776.55	70666050000	0.158048
1998	17646.4	2987.6	54	1553.359	83881386000	0.173809
1999	18463	5455	61.5625	1552.677	95586677813	0.161886
2000	42491	14838	50.125	2702.435	1.3546E+11	0.23878
2001	45657	18669	47.46	2716.477	1.28924E+11	0.261523
2002	44791	9288	38.75	2743.026	1.06292E+11	0.296466
2003	39413	5967	35.08	2767.76	97093020800	0.288727
2004	35674	3593	40.51	2769.652	1.12199E+11	0.241248
2005	31869	7141	30.12	2763.409	83233879080	0.276874
2006	28646	7715	37.24	2911.505	1.08424E+11	0.208987
					Avg Debt/Value (D/V)	0.221639

Table 5.3.3 – Capital Structure for Verizon Wireless

AT&T						
Year	LT Debt	Current Liab	Yr. End Cl	Shares Out	Market Value of Equity	D/V
1995	5672.3	1679.5	57.25	609.36	34885860000	0.139856
1996	5505	1722	51.875	599.866	31118048750	0.150315
1997	13019	1953	73.25	918.641	67290453250	0.16211
1998	12612	1551	53.625	1959.315	1.05068E+11	0.107172
1999	18475	3374	48.75	3395.372	1.65524E+11	0.100408
2000	16492	10470	47.75	3386.709	1.61715E+11	0.092544
2001	17133	9033	39.17	3354.216	1.31385E+11	0.11536
2002	18536	3505	27.11	3317.641	89941247510	0.170875
2003	16060	1879	26.07	3305.236	86167502520	0.157101
2004	21231	5734	25.77	3300.912	85064502240	0.199736
2005	26115	4455	24.49	3876.884	94944889160	0.21572
2006	50063	9733	35.75	6238.746	2.23035E+11	0.183315
					Avg Debt/Value (D/V)	0.149543

Table 5.3.4 – Capital Structure for AT&T

Sprint – Nextel						
yeara	LT Debt	Current Liab	Yr. End Cl	Shares Out	Market Value of Equity	D/V
1995	3253	2424.4	39.625	349.2	13837050000	0.190344674
1996	2981.5	299.1	39.875	430.1	17150237500	0.148099487
1997	3748.6	131	58.625	430	25208750000	0.129452453
1998	4682.8	33.3	84.125	430.7	36232637500	0.114450689
1999	4531	902	67.3125	874.2	58844587500	0.071494406
2000	3482	1026	20.3125	884.6	17968437500	0.162327691
2001	3258	2056	20.08	931.9	18712552000	0.148289401
2002	2736	1234	14.48	938.2	13585136000	0.16763539
2003	2627	-882	16.42	904.3	14848606000	0.150323829
2004	15916	1288	24.85	1474.8	36648780000	0.302788293
2005	20632	5047	23.36	2923	68281280000	0.232046326
2006	21011	1143	18.89	2897	54724330000	0.277426665
					Avg Debt/Value (D/V)	0.174556609

Table 5.3.5 – Capital Structure for Sprint-Nextel

Determination of Cash Flows

- Annual Cash Flows, CF_t

The projected annual cash flows are established as

ΔCF_t = (Revenues – Operating Expenses & Costs)$_t$ (1 – t)

We estimate the incremental annual revenues based on the following assumptions:

(i) The future revenues in the wireless industry will continue to grow ar the historical growth rate. In table 5.3.6, we estimate the base case historical growth rate to be **20%** using the revenue data from 1995 – 2007 [15].

(ii) The incremental revenues from the investment in the Cognitive Systems, net of cannibalization, are **15%** of the projected revenues. The incremental revenues begin in 2011, according to our specified time-line in Fig. 2.1

We estimate the Operating Expenses & Costs based on historical data (2000 – 2004) [16] of Verizon, Sprint, AT&T and SBC. From Table 5.3.7, the base case estimate of Operating Costs and Expenses is **85%** of the incremental revenues.

A tax rate of **35%** is assumed

Year	Estimated Total Subscribers	Total Revenue	Growth rate of number of subscribers	Growth Rate in revenues(%)	Growth Rate in Revenues
1995	28154414	16460516	0.46	30.72	0.31
1996	38195466	21525861	0.36	30.77	0.31
1997	48705553	25575275	0.28	18.81	0.19
1998	60831431	29637742	0.25	15.88	0.16
1999	76284753	37214819	0.25	25.57	0.26
2000	97035925	45295550	0.27	21.71	0.22
2001	118397734	58726376	0.22	29.65	0.30
2002	134561370	71117599	0.14	21.10	0.21
2003	148065824	81185272	0.10	14.16	0.14
2004	169467393	95515593	0.14	17.65	0.18
2005	194479364	108534727	0.15	13.63	0.14
2006	219652457	118299682	0.13	9.00	0.09
2007	243428202	132893824	0.11	12.34	0.12
				Growth Rate (g)	0.2

Table 5.3.6 – Statistics for the Wireless Telecommunication Industry

Verizon	2004	2003	2002	2001	2000		Average
Revenue	71283	67625	67625	67190	64707		
COGS	58166	52628	52628	55658	47949		
COGS as % of revenue	81.5987	77.82329	77.82329	82.83673	74.10172		78.83675

Sprint	2004	2003	2002	2001	2000		
Revenue	27428	26197	26634	26071	23613		
COGS	27731	25336	24534	26733	23108		
COGS as % of revenue	101.1047	96.71336	92.11534	102.5392	97.86135		98.0668

AT&T	2004	2003	2002	2001	2000		
Revenue	30537	34529	37827	52550	65981		
COGS	40625	30872	33466	48796	61704		
COGS as % of revenue	133.0353	89.4089	88.4712	92.85633	93.51783		91.06356

SBC	2004	2003	2002	2001	2000		
Revenue	40787	49843	43138	45908	51476		
COGS	34886	34374	34515	35020	40733		
COGS as % of revenue	85.53215	68.96455	80.01066	76.283	79.13008		77.98409
					Industry average =		86.4878

Table 5.3.7 – Operating Expenses & Costs as a percentage of revenue for some of the major Telecommunication companies

- <u>Terminal Value, TV_N</u>

  The incremental annual cash flows are projected over the period 2011 to 2020. The terminal value is the present value in year N = 2020 of all cash flows beyond the projection horizon. We analyze three scenarios for the terminal value.

  (i) Terminal Value = 0, i.e. there is no (salvage) value to the investment after 2020.

  (ii) The cash flows after year 2020 are a level perpetuity with a terminal growth rate, g = 0. That is, the cash flows after 2020 continue at the 2020 level.

  $$TV_N = CF_{20} / wacc$$

  (iii) The cash flows after year 2020 are a growth perpetuity with a terminal growth, g = 2%. That is, the year 2020 cash flows continue to grow at 2% in steady state.

  $$TV_N = CF_{20} (1 + g) / (wacc – g)$$

Base Case NPV analysis:

As explained earlier, we use the NPV analysis to establish an upper bound on the investment in R&D and infrastructure to ensure a positive NPV.

$$I < PV(CF_1^*, CF_2^*, ……, CF_t^*) + PV(TV_N)$$

The primary inputs to the base case analysis are –

wacc = 10%

Industry revenue growth = 10%

Incremental future revenues = 15% of industry revenue

Operating Expenses & Costs = 85% of incremental revenues

Terminal Value:
(i) 0
(ii) based on terminal g = 0
(iii) based on terminal g = 2%

From Table 5.3.8 (a),(b) and (c), the upper bounds on the investments are:

(i) $ 41.5 M for $TV_N = 0$

(ii) $ 91 M for TV_N with g = 0%

(iii) $ 116 M for TV_N with g = 2%

Thus, higher terminal values allow higher maximum investments while ensuring NPV = 0.

Table 5.3.8 (a) - Base Case Analysis: Scenario 1: Terminal Value = 0

	CF 08	CF 09	CF 10	CF 11	CF 12	CF 13	CF 14	CF 15	CF 16	CF 17	CF 18	CF 19	CF 20
Revenues	159304774.3	190964564	228916332	274410529	328946118	394319957	472686013	566626322	679236067	814225560	976042492	1170018472	1402544701
Incremental CF (Revenue to primary users)		0	0	41161579	49341918	59147994	70902902	84993948	101885410	122133834	146406374	175502771	210381705
Incremental Costs (Administration & Regulatory fees)	0	0	0	34987342	41940630	50275795	60267467	72244856	86602598	103813759	124445418	149177355	178824449
EBIT	0	0	0	6174236.9	7401287.6	8872199	10635435	12749092	15282811	18320075	21960956	26325415.6	31557255.8
EBIT(1-t)	0	0	0	4013254	4810837	5766929.4	6913032.9	8286910	9933827.5	11908049	14274621	17111520.2	20512216.3

CapEx Allowable (No Salvage value)	$41,597,987.33

Table 5.3.8 (b) - Base Case Analysis: Scenario 2: Terminal Value growth rate = 0%

	CF 08	CF 09	CF 10	CF 11	CF 12	CF 13	CF 14	CF 15	CF 16	CF 17	CF 18	CF 19	CF 20
EBIT {terminal growth rate = 0%}	0	0	0	6174237	7401288	8872199	10635435	12749092	15282811	18320075	21960956	26325416	2.95E+08
EBIT(1-t) {terminal growth rate = 0%}	0	0	0	4013254	4810837	5766929	6913033	8286910	9933827	11908049	14274621	17111520	1.92E+08

Cap Ex Allowable (zero terminal growth rate)	$91,163,966.01

Table 5.3.8 (c) - Base Case Analysis: Scenario 3: Terminal Value growth rate = 2%

	CF 08	CF 09	CF 10	CF 11	CF 12	CF 13	CF 14	CF 15	CF 16	CF 17	CF 18	CF 19	CF 20
EBIT {terminal growth rate = 2%}	0	0	0	6174237	7401288	8872199	10635435	12749092	15282811	18320075	21960956	26325416	4.26E+08
EBIT(1-t) {terminal growth rate = 2%}	0	0	0	4013254	4810837	5766929	6913033	8286910	9933827	11908049	14274621	17111520	2.77E+08

Cap Ex Allowable (2% terminal growth rate)	$115,868,717.25

<u>Sensitivity analysis with Monte-Carlo simulations</u> –

The point estimates of cash flows, discount rates, growth rates, etc. which we have deduced are not exact estimates. Some amount of uncertainty always comes into the picture when we try to project cash flows for the future.

So, rather than having point estimates, we like to deal with a specific range within which these estimates may lie. In order to achieve this objective, we run Monte-Carlo simulations using "Crystal Ball™" as the software tool developed by Oracle©. In these simulations, rather than considering precise values, we specify probability distributions for all the input parameters. We then run the simulations for 1000 trials. During each trial, a random value of the input parameter is generated and used in determining the output. Thus, the result is a probability distribution of the output (Cap. Ex allowable)

<u>Probability distributions for the input parameters</u> –

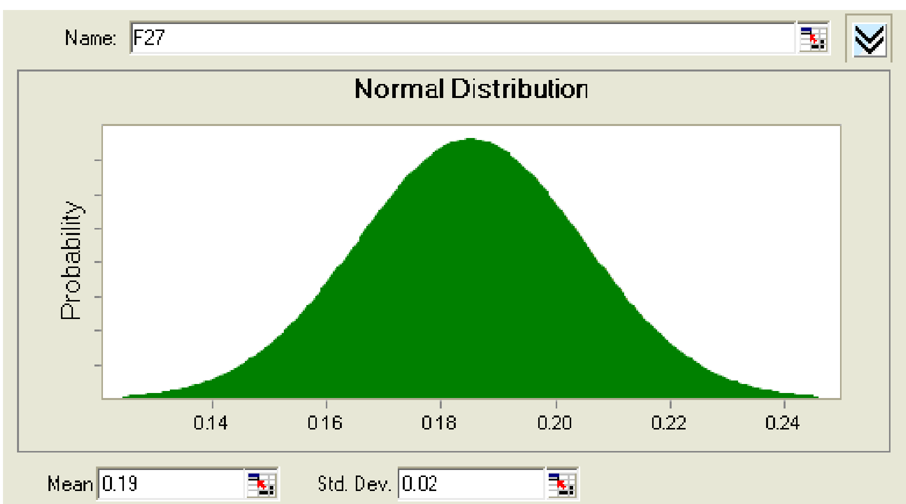


Fig 5.3.6

Revenue
Growth rate (g)

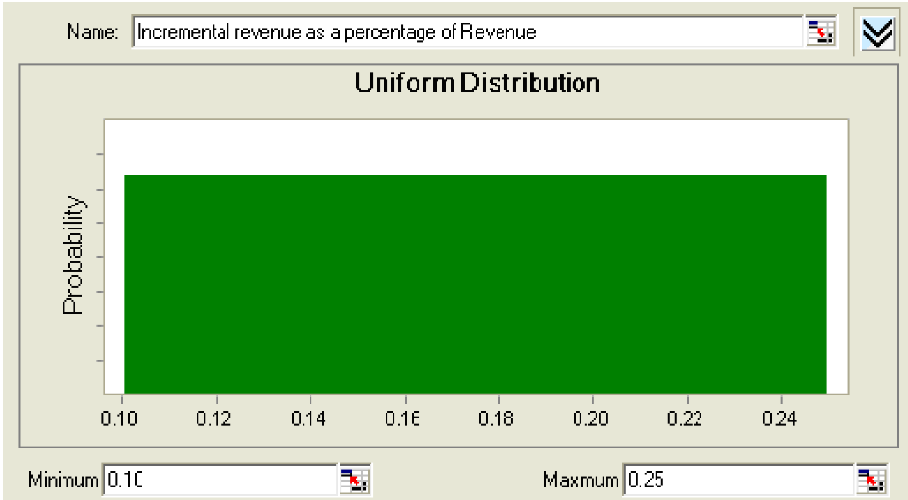


Fig 5.3.7

Incremental revenue from capital investment as a % of revenue

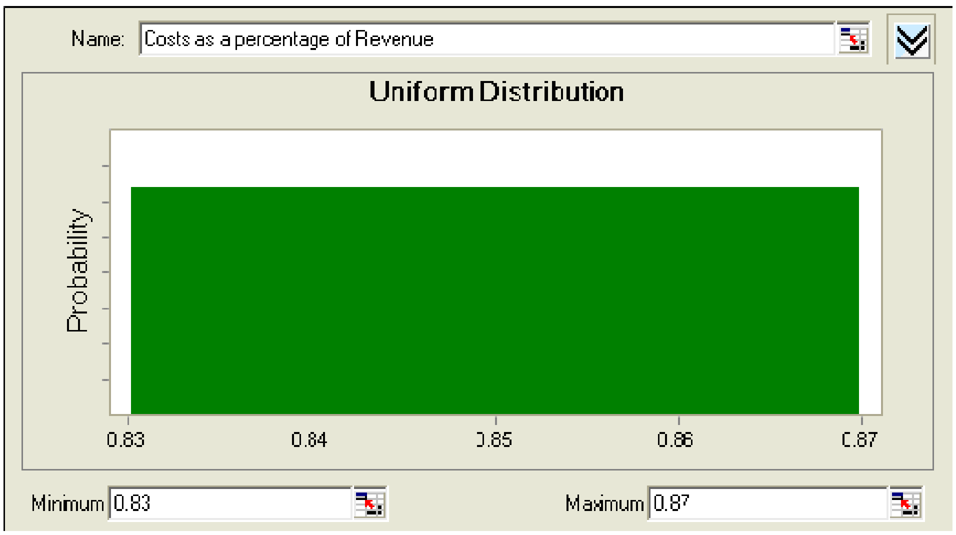


Fig 5.3.8

Operating costs and expenses as a % of revenue

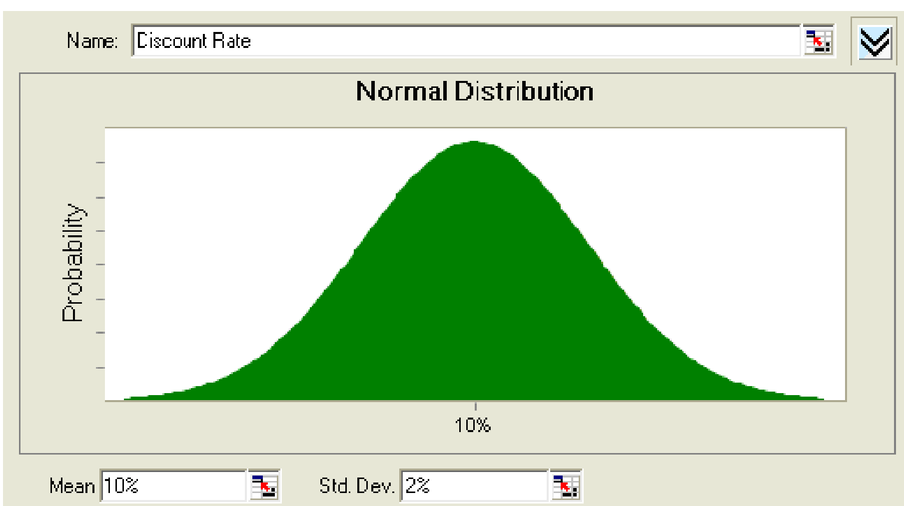


Fig 5.3.9

Discount rate (k)

Probability Distribution generated for the output (Allowable Investment) –

We carry out the NPV calculations and hence calculate the allowable Investment for the three scenarios of terminal value –

1) No Salvage value for the technology after 2020 (Most conservative)

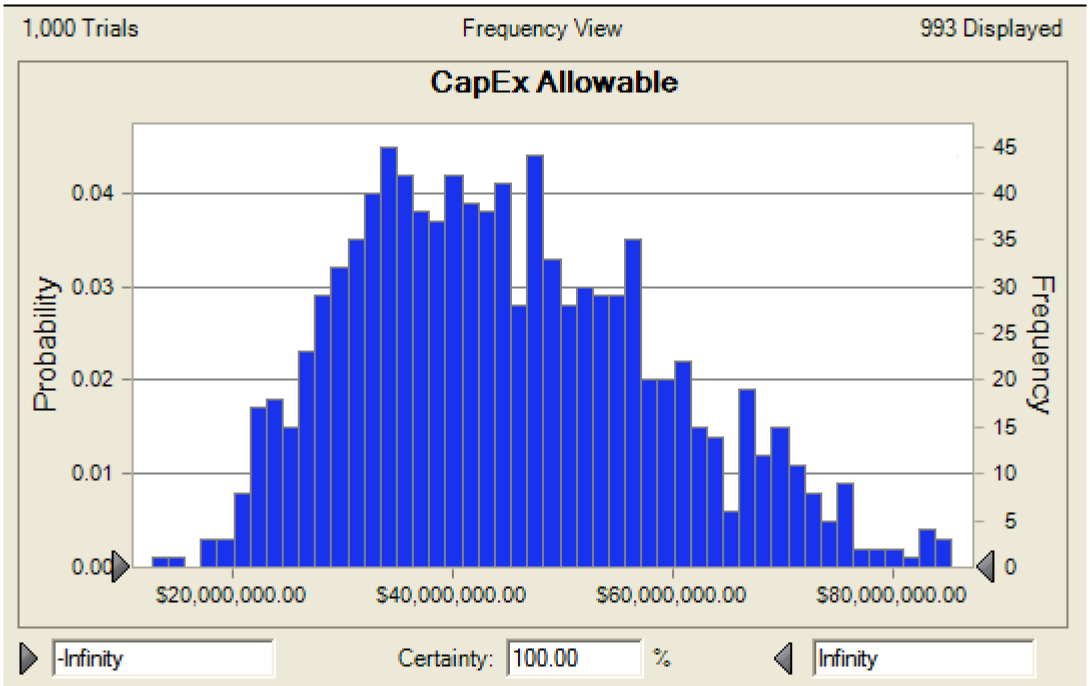


Fig 5.3.10 – No salvage value

2) Salvage Value with a terminal growth rate of g = 0%

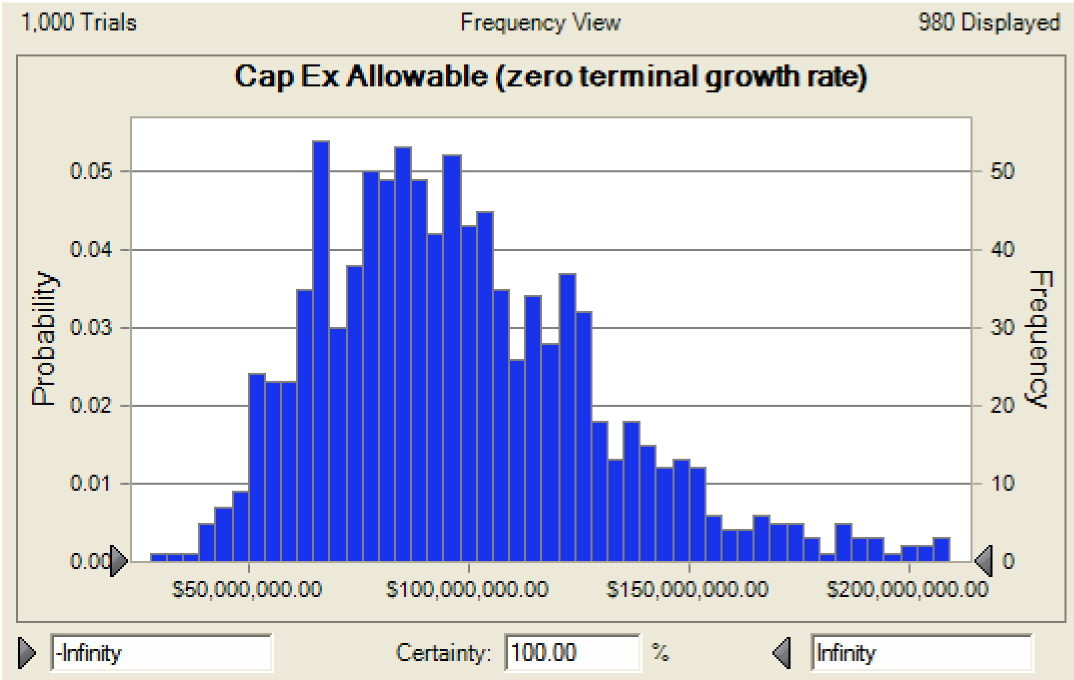


Fig 5.3.11 – Salvage value with 0% terminal growth rate

3) Salvage Value with a terminal growth rate of g = 2%

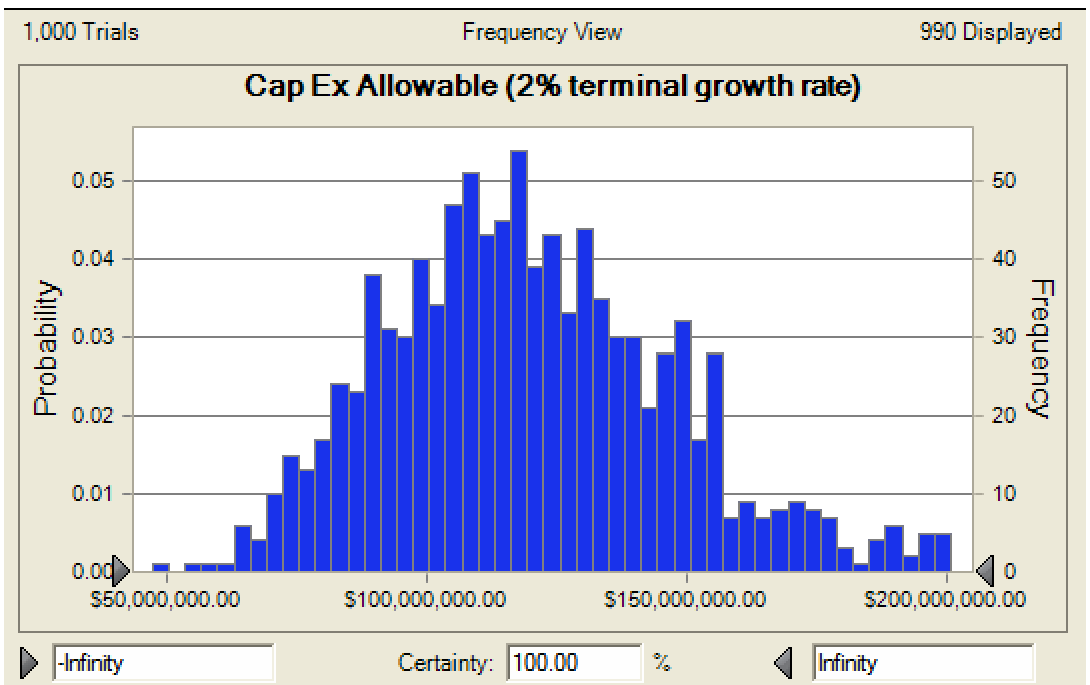


Fig 5.3.12 – Salvage value with 2% terminal growth rate

5.3.4) Real Options Valuation

Senior management often green light a project with a negative NPV.

This is because the traditional DCF techniques fail to incorporate operating and strategic flexibility, i.e., the option to alter a planned course of action in the future based on valuable evolving information. It assumes, for example, that management initiates capital projects immediately and operates it continuously at the base scale until the end of its pre-specified useful life.

In the actual market place, management may have valuable flexibility to alter its initial operating strategies in order to capitalize on favorable future opportunities or to react so as to mitigate losses.

Such operating flexibility with real asset as the underlying asset is called a "real option".

The real option gives its holder the right but not the obligation to buy (call option) or sell (put option) a designated underlying real asset at a pre-determined (exercise) price at a specified (maturity) date (European) or at any time before the maturity date (American).

A corporate investment opportunity is like a call option because the corporation has the right, but not the obligation, to acquire or build, say, a project. There is a correspondence between the project's characteristics and the five variables that determine the value of a simple European call option:

$$C = f(\underset{-}{X}, \underset{+}{S}, \underset{+}{\sigma}, \underset{+}{t}, \underset{+}{r_f})$$

- The amount expended corresponds to the option's exercise price (X)
- The present value of the asset built or acquired corresponds to the stock price (S), the value of the underlying asset
- The length of time the company can defer the investment decision without losing the opportunity corresponds to the option's time to expiration (t).
- The uncertainty about the value of the project's cash flows (the risk of the project) corresponds to the standard deviation of returns on the stock (σ)
- The time value of money in both cases is the risk free rate of return (r_f)

While the firm is waiting to exercise the option, i.e., make the capital expenditure, the asset value may change and affect the decision for the better.

If value goes up, the firm makes the investment or exercises the option. If the value goes down the firm may decide to leave the option unexercised. By waiting, the firm avoids making what would have turned out to be a bad investment. The firm participates in good outcomes and avoids bad ones.

In our case, the primary user can defer the infrastructure investment in the implementation of new technology. The investment can be done in two stages:

First stage:
Investment in R&D and a small upfront investment is made to set-up a small network which provides cognitive capabilities. Secondary access is then provided using this network. At the same time, a real option is purchased which gives the primary user the right but not the obligation to implement the entire network at a future date with the required investment 'I_{future}' (option to expand).

Second stage:
If the test network performs well and generates a sufficient demand for secondary access, the primary user can exercise the option and set-up the entire network. It is also possible that during the test period, the primary user might come up with a more cost-efficient architecture or some regulations might be imposed by the FCC which favors secondary access. As a result, a previously negative NPV project might turn into a positive NPV project. In the worst case scenario, if the situation really gets worse and the test case is not generating sufficient revenues, the implementation of the new technology can be passed over.

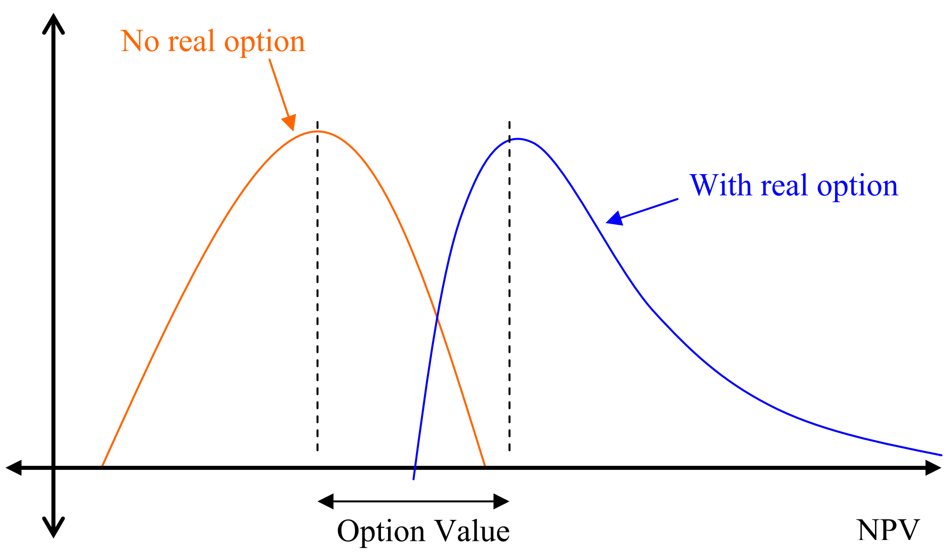


Fig 5.3.13 – Real Option Valuation

5.4) Value Proposition Layer

This layer tries to identify the value proposed to the end-user by implementation of cognitive networks and DSA techniques.

Positioning:

Positioning a product or technology can be a complex issue. Many choices and trade-offs can be identified. One of the most basic one seems to be whether to position a product or service as a substitute or a complement to a currently available product of service.

As we have seen the cognitive network technology is a Gen-X technology for the future. The technology will complement the currently offered wireless services. It will do so by making more efficient allocations and usage of the frequency spectrum. Also by dynamically providing network access to secondary users, it will enable these users with no prior network infrastructure to communicate with each other.

Intended Value:

As seen above, both the primary as well as the secondary users will benefit from the implementation of cognitive networks – the primary users from the incremental revenue provided and the secondary users from the on-the-fly access to spectrum and network usage. By efficiently utilizing the scarce frequency spectrum, the technology also has an associated social benefit.

The end-value of the service provided will also depend on the functional architecture used (as discussed at the functional architecture layer) to implement the cognitive networks. In the centralized approach, the resources and hence the value will be concentrated with the network provider. On the other hand, in the distributed approach there is a transfer of value along the value chain from the network provider to the end-user since transmission can take place without the involvement of the base station (and hence the network provider).

However a "finished" value proposition cannot be made for the new technology. Rather, the involvement of the customers (end-users) will play a pivotal role in determining the end value of the networking service provided.

Only a substantial customer involvement will contribute towards constructing the value of the new technology. Below we provide the market cycles outlined by Chapin and Lehr [18]. They succinctly detail how the DSA technology can efficiently evolve and find success in the market.

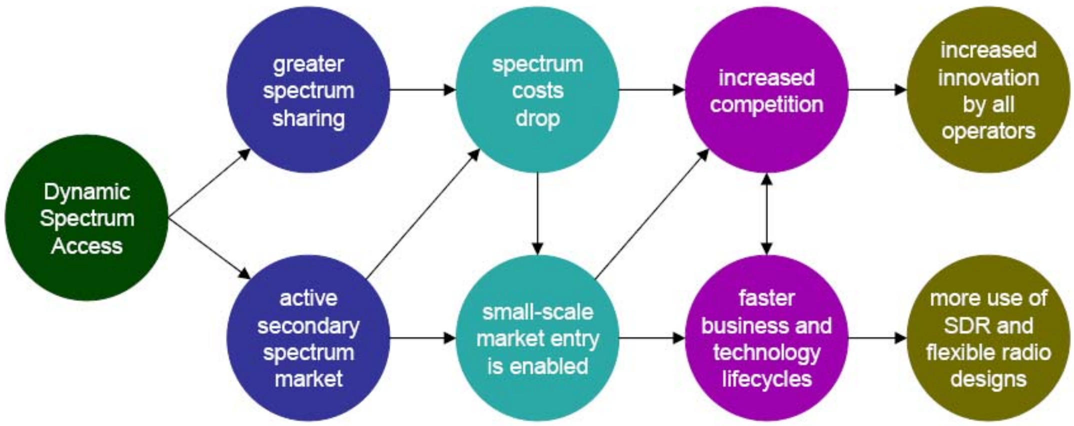


Fig 5.4.1 – Market Dynamics result from widespread use of DSA technology
Source: Chapin, Lehr [18]

Fig 5.4.2 – Feedback loops for growth in use of DSA techniques
Source: Chapin, Lehr [18]

6) Future Research

Dynamic Interaction of spectrum prices in different DSA schemes:

In our model, we have not accounted for one effect – The inter-relation between the prices P_Y and P_Z. These prices are not only dependent on the demand and supply curves but are also inter-related to each other. We try to first find out how these prices relate to each other. Since the cognitive network technology has not been implemented, there is no way of finding even ball-park quantification for P_Y and P_Z.

DSA 3 offers only intermittent access to the secondary users as opposed to a continuous access offered on a long term basis by DSA 2. Also, the secondary user will incur higher system costs in DSA 3 because of the need of precise sensing in this technique. The above factors may cause the secondary user to pay less (P_Z) for DSA 3 as compared to P_Y for DSA 2. However, the final price relationship between DSA 2 and DSA 3 will still be determined by the respective demand-supply curves for the two technologies.

Table 6.1 summarizes a possible scenario when the technology is actually implemented

	DSA – 2	DSA – 3
Revenue generated for the primary user	High	Low
System costs for the secondary user	Low	High

Thus, from the perspective of the secondary user there is a trade-off between the system costs and the spectrum price to be paid to the primary user.

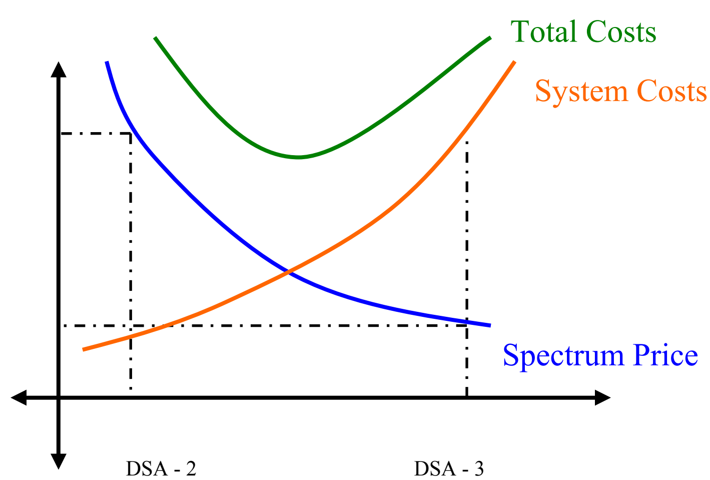


Fig 6.1 – Trade-off for the secondary user between system costs and spectrum fees

The quantity of each DSA technique demanded by the secondary user can be obtained as the optimum point where Marginal Total Costs = Marginal Benefits.

We see that the quantity of each dynamic spectrum access technique supplied by the primary user and demanded by the secondary user depends on the usage price charged for each technique.

In economics, **elasticity** measures the proportional change in one variable with respect to proportional change in another variable. Price elasticity is the sensitivity of quantity demanded and supplied to changes in prices.

Hence, we must take this elasticity into account in our incremental cash flows:

ΔCF_t = (Revenues – Operating costs and expenses).(1 – t)

$= [(Q_Y.\Delta t_2.P_Y + Q_Z.\sum \Delta t_3 .P_Z - \text{Cannibalization of } R_0) - O(w_Y,w_Z)](1 - t)$

where,

$Q_Y = q_Y(P_Y,P_Z \mid e(Y) = a, e(Z) = b)$

$Q_Z = q_Z(P_Y,P_Z \mid e(Y) = a, e(Z) = b)$

Here,

$q_Y(P_Y,P_Z \mid e(P_Y) = a, e(P_Z) = b)$: quantity of DSA 2 demanded per unit time; given price elasticity $e(P_Y) = a$ and $e(P_Z) = b$

$q_Z(P_Y,P_Z \mid e(P_Y) = a, e(P_Z) = b)$: quantity of DSA 3 demanded per unit time; given price elasticity $e(P_Y) = a$ and $e(P_Z) = b$

Future research in this field can involve quantification of the elasticity estimates and re-running our model.

References

[1] Ballon, P., Helmus, S., Van de Pas, R.,
"Business models for next generation wireless services"
GigaMobile/D1.3, 2001

[2] The Yankee Group, "The Wireless Access report", 2000

[3] Mitola, "Cognitive radio for Flexible Mobile Multimedia Communications",
IEEE Mobile Multimedia Conference, 1999

[4] Ramming, C., "Cognitive Networks",
Proceedings of DARPATech Symposium, 2004

[5] Sifalakis, M., Mavrikis, M., Maistros, G.
"Adding Reasoning and cognition to the Internet",
Proceedings of the 3rd Hellenic Conference on Artificial Intelligence, 2004

[6] Boscovic, D., "Cognitive Networks"
Motorola Technology position paper,
http://www.motorola.com/mot/doc/6/6005_MotDoc.pdf, 2006

[7] Thomas, R., DaSilva, L., MacKenzie, A., "Cognitive Networks"
IEEE Symposium on New Frontiers in DSA Networks, DySPAN, 2005

[8] Ballon, P., "Business modeling revisited: the config. of control and value"
INFO – "The Journal of policy, regulation and strategy for
Telecommunications", Vol. 9. No. 5, 2007, pg 6-19

[9] Akyildiz, I., Lee, W. Vuran, M., Shantidev, M., "NeXt generation/dynamic spectrum access/cognitive radio wireless networks: A Survey", Computer Networks, Elsevier, 2006.

[10] Harvard Business School Cases
"Note on Alternate Methods for Estimating Terminal value" , June 1998

[11] Value Line Investment Research, http://www.valueline.com/

[12] Wharton Research Data Services, WRDS – Compustat Package
http://wrds.wharton.upenn.edu/

[13] Federal Reserve Statistical Release
http://www.federalreserve.gov/RELEASES/H15/data.htm

[14] Ibbotson, R., Sinquefield, R., "Stocks, Bonds, Bills and Inflation"
2006 Yearbook (Chicago: Ibbotson Associates)

[15] CTIA – The Wireless Association, "Wireless Industry Survey, 2007"
http://www.ctia.org/media/industry_info/index.cfm/AID/10319

[16] FCC Releases, "Statistics of Communications Common Carriers",
2000, 2001, 2002, 2003, 2004

[17] Investopedia, www.investopedia.com

[18] Chapin, J., Lehr, W.
"The Path to Market Success for Dynamic Spectrum Access Technology"
IEEE Communications Magazine, May 2007.

[19] Cao, L., Zheng, H. “Distributed Spectrum Allocation via local bargaining” SECON, September 2005.

[20] Huang, J., Berry, R.A., Honig, M.L.
“Spectrum sharing with distributed interference compensation”
DySPAN, November 2005.

[21] Ma, L., Han, X., Shen, C.C.
“Dynamic Open Spectrum Sharing MAC protocol for wireless ad-hoc n/w”
IEEE Communications Magazine, May 2004.

[22] Sankaranarayan, S., Papadimitratos, P., Mishra, A., Hershey, S.
“A bandwidth sharing approach to improve licensed spectrum utilization”
DySPAN, November 2005.

[23] Zhao, J., Zheng, H., Yang, G.H.
“Distributed coordination in dynamic spectrum allocation networks”
DySPAN, 2005.

[24] Zhao, Q., Tong, L., Swami, A.
“Decentralized cognitive MAC for dynamic spectrum access”
DySPAN, 2005.

[25] Zheng, H., Cao, L. “Device-centric spectrum management”
DySPAN, November 2005.

[26] Brik, V., Rozner, E., Banarjee, S., Bahl, P.
“DSAP: a protocol for coordinated spectrum access”
DySPAN, November 2005.

[27] Raman, C., Yates, R.D., Mandayam, N.B.
“Scheduling variable rate links via a spectrum server”
DySPAN, 2005.

[28] Zekavat, S.A., Li, X.,
“User-Central Wireless system: ultimate dynamic channel allocation”

Appendix

Code for throughput measurements in a wireless test-bed:

A. Client code

```
#include </usr/include/sys/socket.h>
#include </usr/include/sys/time.h>
#include </usr/include/asm/types.h>
#include</usr/include/netinet/in.h>

#include <math.h>
#include <string.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <signal.h>


#define NUMBER_OF_MESUREMENTS_PER_AMOUNT_OF_DATA 100000 /*how often to
measure travelling time with one certain amount of data*/

#define RECEIVE_PORT 2000
#define SEND_PORT 2001
#define BUF_SIZE 1500


int ss = 0; /*Socketdescriptor*/
int cs = 0;
void* buffer = NULL;
long total_sent_packets = 0;


int create_udp_socket(int port) {
      int    s;
      struct sockaddr_in     host_address;
      s=socket(PF_INET, SOCK_DGRAM, IPPROTO_UDP);
      if (s < 0) {
                  perror("socket()");
                  return -1;
                  }
      memset((void*)&host_address, 0, sizeof(host_address));
      host_address.sin_family=AF_INET;
      host_address.sin_addr.s_addr=inet_addr("192.168.2.1");
      host_address.sin_port=htons(port);
      if (bind(s, (struct sockaddr*)&host_address,
      sizeof(host_address)) < 0) {
            perror("bind()");
            return -1;
      }
      return s;
}
```

```
void sigint(int signum)
{
      /*Clean up.......*/

      close(ss);
      close(cs);

      printf("Client terminating....\n");

      printf("Totally sent: %d packets\n", total_sent_packets);
      printf("Totally sent: %d bytes\n", total_sent_packets*1500);
      exit(0);
}

int main(void)
{
      char buffer[BUF_SIZE];
      unsigned char dest_ip[4];
      struct sockaddr_in target_host_address;
      unsigned char* target_address_holder;
      int i,j,k, sent, length;

      /*Init destination IP address*/

      dest_ip[0] = 192;
      dest_ip[1] = 168;
      dest_ip[2] = 2;
      dest_ip[3] = 2;

        printf("Client started, entering initialiation phase...\n");

      /*open sockets*/
      ss = create_udp_socket(RECEIVE_PORT);
      if (ss == -1) {
            perror("socket():");
              exit(1);
      }
      printf("Successfully opened socket for receiving: %i\n", ss);

      cs = create_udp_socket(SEND_PORT);
      if (cs == -1) {
            perror("socket():");
            exit(1);
      }
      printf("Successfully opened socket for sending: %i\n", cs);


      /*establish signal handler*/
      signal(SIGINT, sigint);
      printf("Successfully established signal handler for SIGINT\n");


      /*init target address structure*/
      target_host_address.sin_family=PF_INET;
      target_host_address.sin_port=htons(RECEIVE_PORT);
      target_address_holder=(unsigned char*)
      &target_host_address.sin_addr.s_addr;
      target_address_holder[0]=dest_ip[0];
```

```
	target_address_holder[1]=dest_ip[1];
	target_address_holder[2]=dest_ip[2];
	target_address_holder[3]=dest_ip[3];

	printf("We are in production state, sending packets....\n");

	for (i = 50; i <= 1500; i += 50) {

	for (k = 0; k < NUMBER_OF_MESUREMENTS_PER_AMOUNT_OF_DATA; k++)
	{
	/*fill it with random data....*/
	for (j = 0; j < BUF_SIZE; j++) {
	buffer[j] = (unsigned char)((int) (255.0*rand()/(RAND_MAX+1.0)));
	}
	/*send packet*/
	sent = sendto(cs, buffer, i, 0, (struct sockaddr*)
	      &target_host_address, sizeof(struct sockaddr));
	      if (sent == -1) {
	                          perror("sendto():");
	                          exit(1);
	                        }
	total_sent_packets++;
	}
	}
}
```

B. *Server Code*

```
#include </usr/include/sys/socket.h>
#include </usr/include/sys/time.h>
#include </usr/include/asm/types.h>
#include </usr/include/netinet/in.h>
#include <math.h>
#include <string.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <signal.h>


#define RECEIVE_PORT 2000
#define SEND_PORT 2001
#define BUF_SIZE 1500


int ss= 0; /*Socketdescriptor Receive*/
int cs= 0; /*Socketdescriptor Send*/
long length = 0;
char buffer[BUF_SIZE];

/*stuff for time measuring: */
struct timeval begin;
struct timeval end;
struct timeval result;
unsigned long long allovertime=0;
int number = 0;
int number2 = 0;
int count = 0;
```

```
int totaltime = 0;
FILE *fp;


int create_udp_socket(int port)
{
      int    s;
      struct sockaddr_in     host_address;
      s=socket(PF_INET, SOCK_DGRAM, IPPROTO_UDP);
      if (s < 0) {
            perror("socket()");
            return -1;
      }
      memset((void*)&host_address, 0, sizeof(host_address));
      host_address.sin_family=AF_INET;
      host_address.sin_addr.s_addr=inet_addr("192.168.2.1");
      host_address.sin_port=htons(port);
      if (bind(s, (struct sockaddr*)&host_address,
      sizeof(host_address)) < 0)
      {
            perror("bind()");
            return -1;
      }
      return s;
}


void sigint(int signum)
{
      /*Clean up.......*/

      close(ss);
      close(cs);


      printf("Server terminating....\n");
      fprintf(fp, "\nBytes:%d\nTime:%d\n",
      number*1500,allovertime/1000000);
      fclose(fp);
      printf("\n\n\n\nTotally received: %d packets\n", number);
      printf("Totally received: %d bytes\n", number*1500);
      printf("Totally time: %d seconds \n", allovertime/1000000);
      exit(0);
}


int main(void)
{
      struct sockaddr_in host_address, target_host_address;
      int hst_addr_size = sizeof(host_address);
      char buffer[BUF_SIZE];
      int length = 0;

      printf("Server started, entering initialiation phase...\n");

      /*open Socket for receiving*/
      ss = create_udp_socket(RECEIVE_PORT);
      if (ss == -1) {
            perror("socket():");
              exit(1);
      }
```

```
printf("Successfully opened socket for receiving: %i\n", ss);

/*open Socket for sending*/
  cs = create_udp_socket(SEND_PORT);
if (cs == -1) {
      perror("socket():");
      exit(1);
}
printf("Successfully opened socket for sending: %i\n", cs);

/*establish signal handler*/
signal(SIGINT, sigint);
printf("Successfully established signal handler for SIGINT\n");

srand(time(NULL));
printf("We are in production state, waiting for incoming
        packets....\n");
fp = fopen("output106.dat", "w");

while (1) {
         /*clear the timers:*/
         timerclear(&begin);
         timerclear(&end);

         /*get time before sending.....*/
         gettimeofday(&begin,NULL);


        /*Wait for incoming packet...*/
        length = recvfrom(ss, buffer, BUF_SIZE, 0, (struct
        sockaddr*)&host_address, &hst_addr_size);

        if (length < 0) {
        perror("recvfrom():");
        exit(1);}

        number++;
        number2++;

        /*get time after sending.....*/
        gettimeofday(&end,NULL);
        /*...and calculate difference.........*/
        timersub(&end,&begin,&result);

        allovertime += ((result.tv_sec * 1000000 ) +
                        result.tv_usec );

        totaltime = allovertime/1000000;
        if(totaltime>count)
        {
        printf("Received: %d packets in %d second \n", number2,
               count);
        fprintf(fp, "%d\t%d\n", count, number2*1500);
        number2=0;
        count++;
        }
 }
}
```