Evolution of Technological Capabilities:
A Study on Indian Product based Telecom Start-up Firms

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Abstract

New technology based start-ups play a very important role in developing the economy of a country. However, product based B2B start-ups in India are rare and existing ones have to undergo several challenges in commercializing. Present study explores the evolution of technological capabilities that enable commercialization among such early stage start-ups by adopting a multiple case based (four independent start-ups) inductive methodology with Indian telecom start-ups as the context. We have identified architectural design, algorithmic implementation and product adaptation as components of technological capability of such start-ups. We explore the link between knowledge acquisition, telecom specific knowledge and capability evolution in present work in a regulated and knowledge intensive context. Finally, we put forth a three stage framework mapping the evolution of technological capabilities among telecom start-ups, as well as identify regulatory bodies, standard making bodies and social network as facilitators in the capability evolution process.

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1. Introduction:

Technology based new ventures have been known to play a significant role in the development of economy of any country especially in today's knowledge based environment. It has been shown by extensive research that such new firms grow more and distribute wealth more effectively as compared to established firms (Schumpeter, 1934, 1942; Wagner, 1994; Tether and Massini, 1998; Brixy and Kohaut, 1999). In the Indian scenario telecom as a sector has shown consistent double digit growth since 2002 (IIR, 2009). This growth coupled with rapid technological changes and changing customer preferences have led to several business opportunities. As a result several telecom related start-ups have sprung up across the country. However, most such start-ups have a services outlook as they have spun off from the Information Technology sector of India which has established itself as the back office for most services being offered across the globe. Although telecom equipment market for 2008-09 in India has touched USD 30 billion[1] but still firms have been reluctant to enter high end product market due to high technological skill requirements, capital intensiveness, time consuming nature of product development related to telecom and lack of adequate marketing skills among start-up firms.

Commercialization marks a very important milestone for any start-up in its lifecycle with a substantial number failing to make the mark. Present work looks into understanding the evolution of technological capabilities among product based telecom start-ups leading to commercialization. These start-ups have telecom/Internet service providers (TSP/ISPs) or other enterprises as customers and so are business to business (B2B) firms. Such Indian telecom start-ups face several problems in their quest to commercialize with their limited funding and un-supportive ecosystem. Moreover competition to such players comes from deep pocketed multi nationals (MNCs) which make such firms more vulnerable. But these start-ups need to be nurtured as they are bound to play an important role in the Indian economy. According to Indian telecom equipment manufacturers' association (TEMA) the telecom equipment and software industry could generate 10 million jobs directly or indirectly and contribute to 10% of total gross domestic product (GDP). Our work contributes to theory development related to knowledge acquisition and capability evolution among B2B technology start-ups with telecom as context.

The paper is organized as follows. We begin with a brief literature review to emphasize on our research context, and then we discuss our methodology, present brief case descriptions and discuss

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[1] Source TEMA website, http://tematelecom.net/upload_images/315TEMA.pdf accessed on 16/09/2009

our analysis framework. We then analyze data from our case studies to understand evolution process of identified technological capabilities. We finally end with conclusions and discussion for future work.

2. Literature review:

The literature on capability evolution has the resource-based view or RBV at its core. RBV identifies heterogeneity among the firms due to valuable, rare, inimitable, and non-substitutable resources as the source of sustainable competitive advantage (Amit and Shoemaker, 1993; Barney, 1991; Wernerfelt, 1984; Peteraf, 1993) and views firms as bundles of resources. RBV has been extensively used to explain the differences in performance of firms in same sectors which is attributed to idiosyncratic or tacit internal capabilities. Over the years conceptual and empirical work has established that the development of capabilities is difficult, time consuming, expensive and risky because the outcomes may be highly uncertain (Dierickx and Cool, 1989; Helfat, 2000; Karim and Mitchell, 2000).

Over the years scholars have looked at technological capabilities in different ways. Conceptually, Bell and Pavitt (1993) define technological capabilities as the resources needed to generate and manage technological change, including skills, knowledge and experience, and institutional structures and linkages. Dosi and Teece (1993) added a more operational perspective when they defined technological capability as the ability to develop and design products and processes, and to operate facilities effectively. Patel and Pavitt (1997) explored the technological capabilities present among 400 of the world's largest firms and conclude that technological capabilities among such firms are multi-field, highly differentiated and stable, and rate of search is influenced by principal product and home country. Patel and Pavitt's work also points to complexity, path dependence and the technological diversity of the established companies as the companies seem to own patents not just in their principal product area but also other allied and even non-allied areas. However, these works do not dwell deeper to identify technological capabilities within a particular industry or firm level capabilities or the evolution of those capabilities.

Among work focusing on an industry level, Prencipe (2000) has operationalized technological capability as breadth and depth of technology among engine control systems in aircraft industry, with breadth referring to the diverse technological fields in which the firm is active and the depth dimension dealing with different levels of component design. Figueiredo (2002) has studied technological capability among two Brazilian steel manufacturers and identified differing technological capability accumulation paths adopted by the firms and further utilized the framework to point out inter-firm capability differences. Afuah (2002) has studied firm's technological capability in the context of pharmaceutical industry and tried to map these capabilities into customer value and

competitive advantage. Other significant work operationalizing technological/R&D capability has been stochastic frontier estimation (SFE) (Dutta et al, 2005) approach wherein capability is conceptualized as efficiency in the transformation of input in to outputs relative to a benchmark firm. Many other industry focused empirical works (Henderson and Clark, 1994; Yeoh and Roth, 1999) have operationalized the technological/R&D capabilities in terms of patents or R&D expenditure to establish the important link between technological capability of the firm and firm performance. However, none of the above scholarly works have looked at telecommunication industry in particular and although industry focused literature is more informative but it is completely focused on the established firms with none focusing upon technological capabilities among the start-ups.

Literature on technological capabilities among start-ups is scarce and like in the case of established firms is focused on citations (Deeds et al., 2000), patents (Tsai, 2004; Lee et al, 1999), R&D labour and R&D expenditure by individual companies as research focus has been developed countries like the US or the UK. But all these parameters including patents, citations and R&D spend are inadequate in the context of Indian and other start-up companies in the developing countries. Most of the times such start-up firms are hard pressed for finances and they actually see patenting as cumbersome and resource intensive process during the early days. In a start-up firm expenditure is essentially on the development work and in this scenario R&D expenditure cannot be separated from development related expenditure. Patel and Pavitt (1997) have pointed out additional limitations of patent and citation based research on technological capabilities such as external technology linkages not getting addressed, tacit component of technology which may actually form the inimitable and valuable component not getting addressed and lastly software related capabilities not getting captured through patents and citations.

Although there is some work focusing on studying the development of general organizational capabilities (Montealegre, 2000; Pan et al., 2006) which tries to bring out the role of managerial and firm action in developing capabilities, literature is not very explicit on the process of evolution of technological capabilities. Stuart and Podolny (1996) use network analytic approach to study the evolution of large Japanese semiconductor companies grouping firms with similar capabilities. Nerkar and Paruchuri (2005) discuss evolution of R&D capabilities at DuPont based on intra-organizational network of inventors and their choice of recombination of technology but this work like Stuart and Podolny's work is based on citation analysis and focused on a large firm. Romijn and Albaladejo (2002) specifically focus on high tech firms in England and statistically bring out that internal determinants such as scientific knowledge and experience and external determinants like network intensity, institutional support play a role in developing technological capability. However, their focus is not the process of evolution of technological capability. An important work in this direction

employing RBV perspective is by Zhai, Shai and Gregory (2006) and they study the evolution of capability among electronic manufacturers based in Far East. They identify stages of growth among these small and medium size firms but none of these firms was really a start-up.

To summarize most work to date has focused on technological capabilities of established firms ignoring the start-ups and none of the earlier works have attempted to understand the process of evolution of technological capabilities among the technology based start-ups. From a theoretical point of view, early stage start-ups present a very crucial and fertile phase to understand the evolution of technological capabilities as it determines the future technological trajectory of the firm due to path dependencies (Cohen and Levinthal, 1990; Zahra and George, 2002). Moreover, there has been no work on telecom sector which involves an intermingling of software and hardware knowledge and is a highly regulated sector not just in India but across the world. In the present work we address the above research gaps and focus on evolution of technological capabilities among telecom start-ups. For the present work we define technological capabilities as follows;

Technological capabilities for telecom start-ups are a collection of skills, resources, routines or processes that enable them to design and develop the desired product and thereby bestow competitive advantage to the start-ups.

Specifically we are looking to answer the following research questions through this work,

1) How do these technological capabilities develop among the product based B2B Indian telecom start-ups that enable commercialization?
2) What is the role played by entrepreneurs and external interventions (competition, regulation etc.) in the evolution of technological capabilities?

3. Methodology:

We use a multiple case based inductive approach to answer the questions posed by us. Pettigrew (1997) has brought out the issue of "process being embedded within the context" and it has been established in capability building literature that capabilities are strongly connected to the context (Grant, 1996; Teece, Pisano, Shuen., 1997; Eisenhardt, Martin 2000; Montealegre, 2002; Pan, Pan, Hsieh, 2006). Case based study is ideally suited to answer questions related to process inquiry as well as answering how and why kind of questions (Eisenhardt, 1989; Yin, 1994). Choice of cases or sampling is a very critical stage for case based studies. Miles and Huberman (1994) have described several ways by which cases can be selected and we resort to maximum variation classification. This maximum variation has been advocated by Eisenhardt (1989) as an aid in ensuring external validity and developing more generalizable theory. Another important issue in case based research is the

number of cases and it has been recommended (Eisenhardt, 1989; Eisenhardt and Graebner, 2007) that rigorous analysis of three to four cases upwards is usually sufficient for theoretical saturation.

We identified 12 companies within the telecom sector (through entrepreneur network) operating in different domains such as voice over Internet Protocol (VoIP) infrastructure development, technology platform for offering value added services, equipment manufacturers, network management. To fulfill our objectives we were looking at the firms with following attributes. The companies had to be product companies looking to sell their end product to either telecom/Internet service providers or other enterprises and none of them was to be purely a services based company. Since we were interested in understanding technological capabilities leading to commercialization, we needed early stage firms which already had customers and were in the market for at least a year. A time window of 3-4 years from inception of the firm was considered adequate as beyond that the firms may move to a growth stage. The companies had to have their registered corporate head offices in India. The reason for the above filter was that companies started out of India would face a different external environment in terms of the ability to raise capital as well as the risk appetite of the entrepreneurs and investors as compared to those based in US or UK. The companies had to be independent and not promoted by any large diversified conglomerate as a company promoted by such group would be a diversification move rather than a start-up company.

We sent letters to all the 12 companies which we identified from their respective websites and sent mails to them identifying ourselves and explaining the purpose of our work. We requested each of the companies to let us have a session with each of the co-founders to understand and assess the evolution of their firms over the years. Of the 12 firms three choose not to respond and two were found to be services oriented firms. Finally, as a part of our classification we chose four firms based on fundamental differences in terms of some of the observable traits (see table 1). As can be seen in the table, firms differ in at least one of the traits from other three firms for each parameter. This would enable greater validity of results from the perspective of theoretical or literal replication (Eisenhardt, 1989). By in depth case studies on four different telecom start-ups we try understand how they went about the process of building technological capabilities.

Among the four companies one of the companies (C3) is no longer in existence and had to be closed down due to various business reasons even before we started our work. This company is of special significance in our work as it could help us in identifying any divergent pattern amongst the other firms. We talked to the co-founders in all cases separately and this also helped in triangulation of data that we collected. Once data was collected the interviews were rigorously transcribed and converted to case histories to focus on the questions to be answered. The case histories so prepared by us were sent

to respective firms for their approval in establishing the chain of events. This was followed by cross case analysis and subsequent conceptualization of the insights gained into a framework for the evolution of technological capabilities among the telecom start-ups. In the next section we present a short description of the four sample firms that we studied.

Table-1: Sample firms with differences across various parameters

Parameter	Company Name			
	C1	C2	C3	C4
Technology	WiMax (wireless)	VoIP	Circuit emulation over Ethernet	Bluetooth (wireless)
Area of operation	Equipment development	Platform development	Equipment development	Platform development
Hardware/software	Both	Software	Both	Both
Incubation	No	Yes (IIT Madras)	Yes (IIT Bombay)	No
VC investment	No	Yes	Yes	Yes
Customers (Tech Vs Non tech)	ISP/TSP (Tech)	ISP/TSP (Tech)	ISP/TSP (Tech)	Community center, retail malls (Non tech)
Patents	Yes (Pending)	No	Yes	Yes (Pending)
Success/Failed	Success	Success	Failed	Success

4. Brief Case Study Descriptions:

4.1 Company C1:

C1 was founded in Bangalore in the year 2005. The two founding members were highly educated with post graduate degrees in technology; one had a MS from US and other was a MS from India. Both founding members were first generation entrepreneurs without any prior start-up experience. The founders worked for well known telecom related companies which included exposure to both hardware as well as software. The main driver of business was that wireless broadband using WiMax would be the way to go for the future and entrepreneurs expected a huge pent up demand for broadband. So the team decided to get into manufacturing of WiMax based He searched the market for investors, had discussions on the business plan within his project team and once convinced of being able to raise some money, together he and his associate founded their own company to pursue this opportunity. One of the founders took on the role of CEO and other became the CTO.

They developed a small base station using the chipset used by Wavesat (semiconductor manufacturer) for their customer premise equipment and that base station could be mounted on a tower or house top. The company went along with its development work and was able to bring its product into the market and is today among admired start-ups in the field of WiMax from India. In 2008, company had about 30 employees and had already sold its product to a company each in Canada and France. C1 mostly sold through a licensing model wherein they licensed their software and recommended specific

hardware to their customers. However, the company could not solicit funds from any venture capitalist and was completely funded by the promoters which has restricted its growth due to lack of funds.

4.2 Company C2:

C2 was founded in the year 2000-2001 in Hyderabad. Both the founders were highly educated with a post graduate degrees in management; one also had a BS degree from IIT in engineering at the under graduate level. Both the founding members were first generation entrepreneurs without any prior start-up experience. One founder had prior experience working for well known software MNC as a project manager and then for an Indian ISP as the business development in-charge related to web services division. Co-founder joined the same ISP as a (fresher) management trainee looking after sales and marketing role for the web services division of the ISP. Both the founders gave up their job to start the new company. The first founder became the CTO and the other was designated as the CMO (Chief Marketing Officer).

During this time regulation was passed making VoIP (Voice over Internet Protocol) services legal between PCs in India to phones, mobiles and PCs abroad. The founders who were developing convergence engine and were trying to develop voice based application found VoIP services to an ideal opportunity for them to be able to use their technological skills. The business idea was to develop VoIP infrastructure for ISPs who already had network and other infrastructure of their own and let them offer the VoIP services using the product developed by the company. The pivotal innovation behind the company was the development of soft switch with de-coupled application server and front end, which allowed easy transition between protocols. C2 became the first company to offer end to end VoIP infrastructure among the Indian companies. Later the company got invested by a VC based in Coimbatore and shifted its base to Chennai under the aegis of the TeNeT group of IIT Madras. The company was also invested by Venture East, the investment arm of TeNeT group. Once the company became a part of TeNeT it could access services offered by IIT as well as technical consulting from the faculty. By 2005 the company had acquired several clients both in India and abroad, had become self-sustainable and was planning to diversify into platform provider for the various telecom service providers. The number of employees stayed around 30 even with a regular attrition from the company. C2 has been one of the pioneers of VoIP products in India and is a unique company of its kind in India.

4.3 Company C3:

C3 was founded in late 2002 in Mumbai. All the three founders were highly educated, one with a PhD in Electrical Engineering from IIT Kanpur, second with post graduate degree in management from an university in US and the third holding a post graduate degree in Electrical Engineering from IIT

Bombay. First founder worked as a faculty member at a leading institute of technology in the Electrical Engineering department and had 5-6 years of consulting experience in the area of networking. Second founder was running a successful family owned business related to manufacturing customer premise telecom equipment such as Modems. The third co-founder had about two years of experience related to software development with a major Indian company. Neither the first nor the second founder gave up his job to start the company; third founder was a fresher and was on a look out for a suitable job.

The driver behind the business was that it was recognized that future networks would essentially be Internet Protocol (IP) based packet networks. Founders of company C3 were looking to develop a multi service interface that could use the existing infrastructure but provide the data, voice and video capabilities with the minimum change in the equipment, with minimum capital expenditure and highest quality of service. They decided to develop with Ethernet at the core of the technology as it was well understood and simple and cost effective to deploy. C3 was able to solicit investment from a US based VC with proven credentials in telecom related investment as well as SIDBI, an India based funding company. The company went forward with its plans of development and did achieve limited success in its development efforts and was able to successfully test its earlier version of product with one of the clients although it faced several problems in manufacturing high end hardware in India. But due to sudden changes in the business environment of its only prospective client coupled with rise of wireless broadband, it could no sustain in the market for long and was shut down in mid-2007. C3 also received a patent for its efforts related to development of an adaptation layer for communicating voice over Ethernet in 2005.

4.4 Company C4:

C4 was founded in Bangalore in the year 2004. The two founding members were highly educated with post graduate degrees in management and graduation in technology (one with electronic engineering and other with computer applications). Both founding members were first generation entrepreneurs without any prior start-up experience. The founders worked for well-known software companies in their telecom software division and also worked for a telecom related start-up in various technical and managerial positions. They could sense a business opportunity for developing sub-components for speeding up product development in companies engaged in mobile applications and this led them to start their own company. One of the founders took on the role of CEO and other became the technical director.

They developed a several components for mobile application development and then in 2005-06 tried to move into m-commerce with a suite of products enabling m-ticketing, logistics etc. However, soon

they realized the lack of volumes in m-commerce related business and moved to Bluetooth based products to reduce their dependence on the telecom service providers. C4 came up with innovative idea of transforming community centers into Bluetooth enabled zones for promotion and advertising over existing mobile handsets. C4 completed its development work by early 2007 and was able to bring its product into the market by converting a famous retail mall in Bangalore as the first Blue-Fi enabled mall in India. C4 subsequently acquired several new clients in the same space. Today C4 is among pioneers of Bluetooth based media companies in India. It not only sets up a Bluetooth network using its product but also maintains the network for their customers. C4 has about 50 employees and mostly sells through a revenue share model where in the retailers pay them a fixed fee for their product and the maintenance of the existing network. C4 received its first external funding to the tune of USD 250,000 from VC's in 2006 and has been looking to spread its Bluetooth zones across a 1000 centers in India.

5. Analysis framework:

We first analyze the entrepreneurs and their characteristics including their education, experience and motivation. This sets the background for the understanding of evolution of technological capabilities as entrepreneurs are the main protagonist in start-ups and are responsible for decision making and setting directions for the future. We briefly present our process of identification of technological capabilities based on analyzing specific technological activities, skills or routine that the firm has accomplished in its own way has played an important role in commercialization or bestowed a competitive advantage. However in the process if some activity is considered below par by the entrepreneurs then we do not consider that activity as contributing towards technological capability. Three important attributes of the activities that could help in identifying technological capability are that the activity should have made critical contribution to the commercialization process, been performed well consistently leading to competitive advantage (Helfat and Peteraf, 2003; Winter, 2000, 2003) and might have evolved into identifiable routines overtime (Nelson and Winter, 1982).

The point we want to emphasize upon is that, just a presence of certain activity cannot make it a capability (Helfat and Peteraf, 2003) but certain level of excellence or maturity has to be achieved with respect to the activity and its outcomes (Winter, 2000). After detailed analysis of identified components of technological capability we present a detailed map of the process of technological knowledge acquisition among the start-ups in telecom sector. From the perspective of presentation we move back and forth between data and theory like it is the standard practice in most works on theory building and extensively utilize vignettes and instances to map the knowledge acquisition process. Having established the knowledge acquisition process we then link it to capability life cycle approach and extend the overall argument to develop a framework for the evolution of technological

capabilities.

However, it needs to be mentioned here that a limitation of the above process is that it has the danger of suffering from entrepreneur's bias towards certain skills or activities as they might be overemphasized in hindsight. We wave tried to minimize the bias by talking to most members of the founding teams and getting their opinions as well thereby achieving triangulation. In cases where this has not been possible we have taken a call based on our understanding of the case.

6. Analysis:

6.1 Entrepreneurial characteristics:

Below we present details of education and prior experience of the entrepreneurs in our study (tables 2 and 3). It can be seen that all the entrepreneurs were highly qualified with post graduate professional degrees in engineering or management. In terms of experience too we can observe a high technological experience elated to telecom but low exposure to marketing related work.

Table-2: Educational details of entrepreneurs

Company	Technical Education	Management Education
C1	Both founding members (PG)	None
C2	One founding member	Both members
C3	All three founding members (PG)	One member
C4	Both members	Both members

Table-3: Details of prior work experience

Company	Founder 1	Founder 2	Founder 3
C1	8+ years telecom MNC Indian telecom s/w firm	8+ years Indian telecom s/w firm	
C2	5 years IT MNC, ISP real time network related application	2 years marketing of bandwidth and real time network applications	
C3	10 years Telecom network related research & consultancy	12 years+, Telecom, low end premise equipment manufacturing (family owned)	3 years IT (s/w development) experience
C4	8+ year telecom related development for IT MNC's and telecom start-ups, also marketing for these start-ups	5+ year telecom related development for IT MNC's and telecom start-ups	

In addition to above in each of the four cases entrepreneurs took up complementary responsibilities depending upon their prior experience. The underlying motivation in each of the cases except C3 was to operate a successful product based technology firm from India. In C3, motivation for starting out as well as the vision for moving further was not aligned as against all the other firms. Even with several disagreements about the way to function none of C1, C2 or C4 had any issues related to overall alignment of the firm.

6.2 Identification of components of technological capability:

In this section we briefly discuss identification of technological capabilities and elimination of non-core activities. A general list of technical activities conducted by the firms has been identified from case descriptions and they include the following activities,

1) Architectural design
2) Prototype development
3) Testing
4) Product adaptation
5) Scale-up of production

The activities we could eliminate as per our analysis framework based on inputs from entrepreneurs include testing, hardware related manufacturing within prototype development and scale-up of production.

a) Testing:

Among all the firms initial focus was not on testing and were started in response to customer requirements for robustness, and mostly included writing of a few test cases by the developers themselves. Among all our case studies the most comprehensive testing was done by the clients when they installed the products in their own network. The usage of automated testing tools was non-existent given the cost of such tools although it is the norm in all established companies. The state of testing has been well summed up by one of the senior employee involved in project management activities at C1,

"I would say that we are only 20% there still 80% improvement is needed, so testing is going on and test process is there but in my opinion it is very basic, primitive… [B]ut there is no precise definition of what is the input, what is the output, what are the different test conditions and mainly there is no automation of test cases which is important".

So based on the above description we can say that testing activities being carried out among the start-ups cannot be categorized as critical or well performed and is not an activity that can be classified as a

candidate for technological capability.

b) Prototype development (hardware manufacturing):

Although firms engaged in end to end design of hardware circuit boards but none of the firs undertook any manufacturing in-house as neither they had the means nor prior experience in hardware manufacturing. It was completely out-sourced to external vendors and so hardware manufacturing within prototype development can be eliminated as technological capability of these start-ups.

c) Scale-up of production:

This activity is more relevant for hardware oriented firms. However, only firm C1 showed an inclination towards scaling up of its production capacity. Firm C1 made its efforts towards establishing material flow of the process, decision making on rules for inventory handling, removing redundancies in the development in order to improve the output. However, the production manager at C1 pointed out that it was very difficult to make the people toe a fixed line and follow processes. Firms C3 and C4 too were looking towards streamlining of production but did not take any concrete steps. With no further evidence regarding scale-up we can not consider this activity as critical or well performed by the firms and as such it cannot be classified as a candidate for technological capability.

Other activities such as architectural design, prototype development (specifically algorithmic implementation) and product adaptation showed strong evidence for being considered as components of technological capabilities. Our criteria of identification brings us to the following results,

Table-4: Identification of technological capabilities

Activity	Identified as critical	Performed well	Routinized	Identified as capability
Architectural design	Yes	Yes	No	Yes
Prototype development (algorithmic implementation)	Yes	Yes	No	Yes
Testing	Yes	No	No	No
Product adaptation	Yes	C1, C2, C4	Limited to C2	Yes
Scale-up of Production	No	No	Limited to C1	No

7. Evolution of technological capability among the telecom start-ups:

We have identified technological capabilities to be manifested in the form of architectural design, algorithmic implementation and product adaptation capabilities. We can say that source of all technological capability is the technical knowledge as none of the above listed three activity sets is actually possible without technical knowledge. Therefore we need to study the evolution of technical

knowledge among the start-ups with time that enables it to perform the above mentioned activities. But before that we examine the specificity of knowledge in telecom sector, entrepreneurial knowledge and prior work experience and finally, its relationship to technological capability development.

7.1 Specificity of telecom related knowledge:

Telecom specific knowledge such as various protocols and their implementation is not easily accessible as it is not imparted through most technical institutes at the under graduate level. According to the entrepreneurs, there is a gap between the requirements of the industry and the kind of training imparted even at post graduate level. One of the primary reasons of telecom protocol related knowledge not being taught at the various technology schools is the ever evolving nature of the protocols. With several different international forums working on different protocols keeping tab on the developments is a very difficult task. Unlike specific training for IT which is carried out by most technical colleges and several big and small private institutes across India such as APTECH or NIIT no telecom specific training institutes function in India. As a result such skill is confined to specific groups within specific firms (both Indian firms and MNCs) or even special centers of excellence such as the TeNeT group situated at IIT Madras or the CDoT (Center for Development of Telematics) a research institute run by Government of India. Apart from such centers, disparate research is also conducted by individuals across various technology institutes. C3 was an example of a company started by such an individual among our sample firms. Not only are these skills less accessible but also they comprise an important tacit component and this knowledge can be picked up only by undertaking development work oneself under the guidance of the other members of the expert groups. According to one of the CTO of our sample firms,

"It is a specific skill set and if I had not joined [company X] I would not have learned this skill. Because of that particular group I had that competence otherwise that will not come for a common man".

Based on this evidence it can be said that telecom specific knowledge is rare, less accessible and has tacit component to it which can be learned only by working in a specific environment.

As a fresher or otherwise, people who are a part of such groups or work in association with such groups are the only ones who can learn the basic skills. This creates a group of individuals or a specific technological community that is the bearer of knowledge offering an access to the telecom sector development. The evidence of the above conjecture is strengthened by the observation that none of the entrepreneurs among our cases was a fresher out of college and all the entrepreneurs had earlier experience with telecom and networking related development or research (see table-2). Based on this discussion we can say that,

Proposition 1: Prior technical work experience among the personnel with end to end development, new product development or protocol design and development among the personnel contributes positively towards the technological capability of the telecom startups.

8.2 Stages of technological knowledge acquisition:

Stage 1:

Prospective entrepreneurs join specific centers of excellence in telecom, telecom MNCs operating from India or even abroad or specific groups in Indian software companies engaged in typical telecom/network related development activities. The relevance of telecom specific knowledge has been already emphasized upon in the last section of this document. On the job training related to the product development, actual protocol implementation etc. helps in acquiring relevant skills. Such groups or centers are run by senior people with long term (10-15 year) experience in the telecom domain and interacting with such senior and well versed people helps in acquisition of tacit knowledge which initiates the new recruits into community of telecom practitioners. As an evidence for the above, according to the CEO of C1,

"I should be thankful to [company X] for that as they allowed a young person like me to carry out those exercises [projects on 3G and UMTS protocols]. Joining [company X] was very good as it gave me an exposure about how the Indian wireless market was shaping up and stuff like that. So I learnt a lot of things especially what to do and what not to do".

According to CTO of C2,

"It is a learning process, see it is not like that it happens in a flash or something, it is like whatever you have done for so long, I had already done certain things [real time networking related development], that as well as based on it".

According to CTO of C4,

"We developed the search tool way back in 2004, we had some challenges because it was the earliest network aware application that we built at that time so it was at the initial stage… we had expertise when it comes to mobile applications because myself and XYZ used to work for another company which was also on core telecom and mobile. So from 1999-2000 XYZ and team have developed and have worked for various firms in the domain".

Borrowing from Nonaka's (1994) model, on an individual level there is a transfer of explicit to explicit knowledge (combination), tacit to tacit knowledge (socialization) as well as explicit to tacit knowledge (internalization) to the new recruits. New recruit often work across several different projects picking up valuable insights and skills not available outside the community. Cross

fertilization of ideas and skills is common not just among the new recruits themselves but also across the hierarchy from senior developer to new recruits. Additionally, the new recruits may be indoctrinated into specific routines or processes followed by the organization. Based on above description we label stage 1 as **foundation** stage.

Stage 2:
Having acquired appropriate work experience and armed with an idea for developing a product in the telecom space the team starts a focused search activity towards getting to know the new skills or new technology that needs to be learned for further fructification of the conceived idea. This search is completely guided by the existing knowledge of the entrepreneurial team. This process of search occurs at different levels for example at the individual level as well as the team or the firm level. The search process may also take the firm to interact with other firms or consultants in order to get access to specific technical knowledge and start-ups forge partnerships for the same. Start-ups in telecom especially with a hardware focus often sign NDA (non-disclosure agreements) with leading semiconductor designers and manufacturers to facilitate transfer of documents related to the chipsets. The documents are a rich source of information related to possible ways in which the chipsets could be put to use. The semiconductor firms also enable access to various tool kits and all this helps in developing new products. Another very potent source of information and facilitator of search among the telecom start-up firms is the Internet. Internet enables access to several forums especially those run by standard setting bodies, chat rooms, blogs, journals, other technology related company websites and whitepapers explaining new developments and new techniques. The following quote by CTO of C2 presents a strong evidence for the same,

"I was actually going through the VoIP things, how to fit this in to that, you can say that the Internet was the only source for me, and enough things were available … there was enough activity going throughout the world, and I hooked myself on that, followed it and thus updated my knowledge about all this [VoIP related development]".

The regulatory environment too provides cues and guidelines to the team especially with regard to specifications that need to be met for the product especially in the case of equipment developers in wireless domain. In this access to sources of knowledge apart from Internet based sources, the social capital of entrepreneurial team including professional acquaintances and friends plays an important role. March (1991) in his seminal work has grouped together search, variation, risk taking, experimentation as exploration. However, here we see a much more focused search aimed at getting to sources of information related to new technology. Based on the above description we label the second stage as **focused exploration**.

Stage 3:

The focused search led to identification of the sources by which information or data could be acquired and can be transformed into knowledge. For transformation to take place the information has to be absorbed and interpreted appropriately by the founding team. This interpretation is brought on by extended debates and discussions among the team members. The members go through the sources of information, analyze the information under the influence of their existing knowledge base and interact together to sort out the technical issues that arise. According to a senior developer at C1,

"In the starting there were three people looking in to this [understanding of WiMax], me, XYZ and ABC we used to discuss a lot and we sometimes used to agree and sometimes agreed to disagree, we used to fight and get things sorted out finally and then we said ok, we will get ahead in this way. So we were the decision makers finally, there was no one who could say, ok you need to go like this, that was a challenge, we had to decide the right path, and if we decided the wrong path we would have to come back to the right path".

Similar evidence is presented by C2, according to the CTO,

"It is internalized in our environment, there is no formal training or anything but essentially the group as a whole they read up the things, there is a small presentation and we sit together and discuss what is it that needs to be done, what are the packets that need to be shot out at what time, what is the basic thing so that is how the things are taken up. In fact in a span of just 10 days you are ready with the design for that. It is done at that high a speed."

This coming together of differing skills and experiences scripts new insights about the conventional products or methods and formulates ways of improving upon the existing products. This also involves further dissemination of insights gained by the few members of the team to other members of the team. The insights gained during such interactions become a part of the organizational memory and help in bringing about a convergence of disparate views about various approaches to be adopted by the team. Overall the team learns new technology together and this sets a shared vision and direction for the team to follow. Based on the above description we label this stage as **assimilation**.

Stage 4:

Once a direction is set the team moves forward to achieve its aim to develop the conceived product. But the team may face several obstacles in actual development process. These problems are overcome by various ways such as bringing prior experience of dealing with similar problem into use, experimentation, hit and trial, and even soliciting help from external consultants. In each of the cases where impediment is faced the team works to identify the

source of the problem by brain storming sessions. This helps not just in problem identification but also helps guiding the team in the solution of the given problem. The insights gained during such instances might become thumb rules or routines for the firm that helps in enhancing the efficiency of the process or the product itself. It is through such instances that the tacit knowledge or specifics related to actual practice are converted into explicit knowledge stock of the firm (externalization) (Nonaka, 1994). This last stage has been labeled as **implementation & assessment**. The prominent learning process during this stage is adaptive learning which happens as a result of iteration between the last two stages of assimilation and implementation & assessment.

At times assessment followed by assimilation may show a requirement for still more focused search to answer the questions or to sort out problems arising during the implementation. This cycle of iteration between focused exploration, assimilation, implementation & assessment moves on and adds on to individual and organizational knowledge which is added to the organizational memory for future retrieval.

The above stages have been depicted in the figure1. The Y axis represents increase in the resources committed to the process of acquiring technical knowledge and there by building technological capability. The increase in resources committed is not just financial but also represents a move from individual to team to more organizational level of knowledge acquisition with rich inputs from social network of the team, other organizations, consultants and regulatory and standard bodies. The X axis represents the time dimension and emphasizes on the path dependence and incompressibility of time period for the evolution of technological capability. The Z axis represents knowledge accumulation through enhancement in the organizational memory.
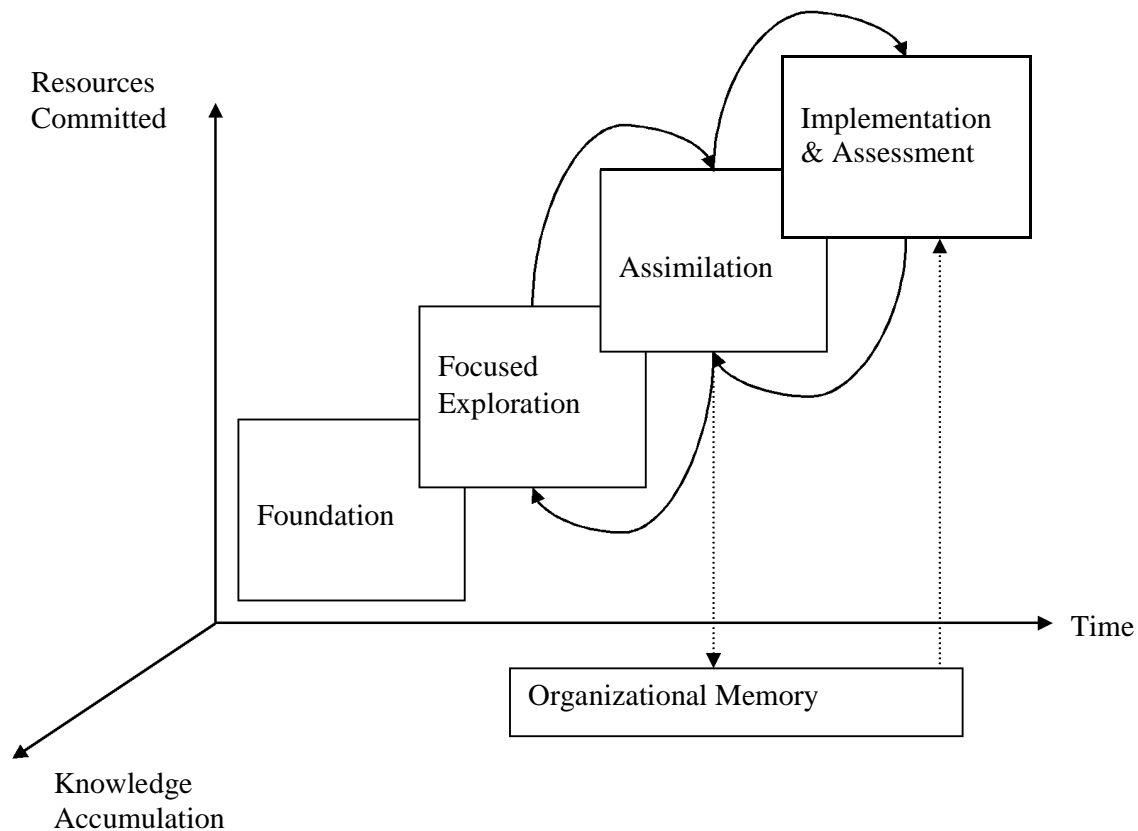
Figure 1: Acquisition of Technological Knowledge

7.3 Framework for technological capability evolution:

The iterative process described in figure 1 above may be referred to as knowledge generating process in our context. We need to link the knowledge acquisition process to the evolution of technological capabilities. This link can be established by invoking the capability life cycle (CLC) concept developed by Helfat and Peteraf (2003). Helfat and Peteraf (2003) argue that each capability is born, evolves, matures and then may die out or branch or recombine to create another capability. Linking the description of stages of knowledge acquisition to the concept of capability life cycle (CLC), we argue that the first few cycles of the process of acquiring and implementing an activity mark the birth of a capability and then subsequent iterations enable the growth and maturation of a capability. We depict this process in the form of three stages labeled as foundation, augmentation and realization (refer figure 2). The figure 2 also describes each stage in terms of three attributes, i.e., knowledge, people and processes as they form integral part of any capability state.

Foundation stage represents the earliest stage of knowledge acquisition as has been described in detail in the section above. This forms the first stage of technological capability development. People involved are only the entrepreneurs and main process involves absorption of knowledge from domain experts. Education of the entrepreneurs plays an important role in their absorbing the telecom specific knowledge. Another significant learning in this stage is introduction to sources of technological knowledge which could be accessed in future. The output of this stage is basic know-how, gaining valuable experience and development of new business ideas.

The second stage has been labeled as **augmentation** as this is the stage where the basic know how is enhanced by first time activities and learning by doing or adaptive learning forms the main process of learning. The transition from foundation to augmentation stage is brought on by earliest cycle of knowledge generating process described in the section above. This stage is instrumental in establishing tentative causalities and early understanding about the technological activities. This stage is mostly confined to entrepreneurs and earliest employees of the firm who together form the core members of the team. The result of this stage is know why based understanding of activities.

The final stage is the **realization** stage where team grows in confidence in achieving desired results consistently in various technological activities. This is achieved by repeated application of the cycle of learning comprising focused exploration, assimilation, implementation & assessment (refer figure 1). This stage also witnesses planned experimentations by the firm to validate their beliefs regarding causality and as a result of this understanding earliest routines start developing. During the stage the team size increases and the founding team is also joined by new group of employees who are guided by the founding team members. This stage marks the birth of technological capability among the start-ups.

Across all four of our sample firms, government regulations and standard making bodies influenced opportunity recognition and product specification. Adopting appropriate standards also helps in building credibility about technological knowledge of the start-ups. Social network of the entrepreneurs including supplier, partners, friends and acquaintances enables

access to vital inputs such as appropriate information, financial resources, technology consultants as well as earliest customers for testing of the product. Incubators and funding agencies (including VCs) further bolster the social network of the entrepreneurs. Across all the stages government regulations, standard forming bodies, social network and competitor's activities facilitate the process of capability development. Based on above discussion we can say that,

Proposition 2: The regulatory regime, standard setting bodies, competitors' activities, and the social network of the entrepreneurs provide critical information, enable access to complementary assets and thus act as facilitators in development of technological capability among the telecom start-ups.

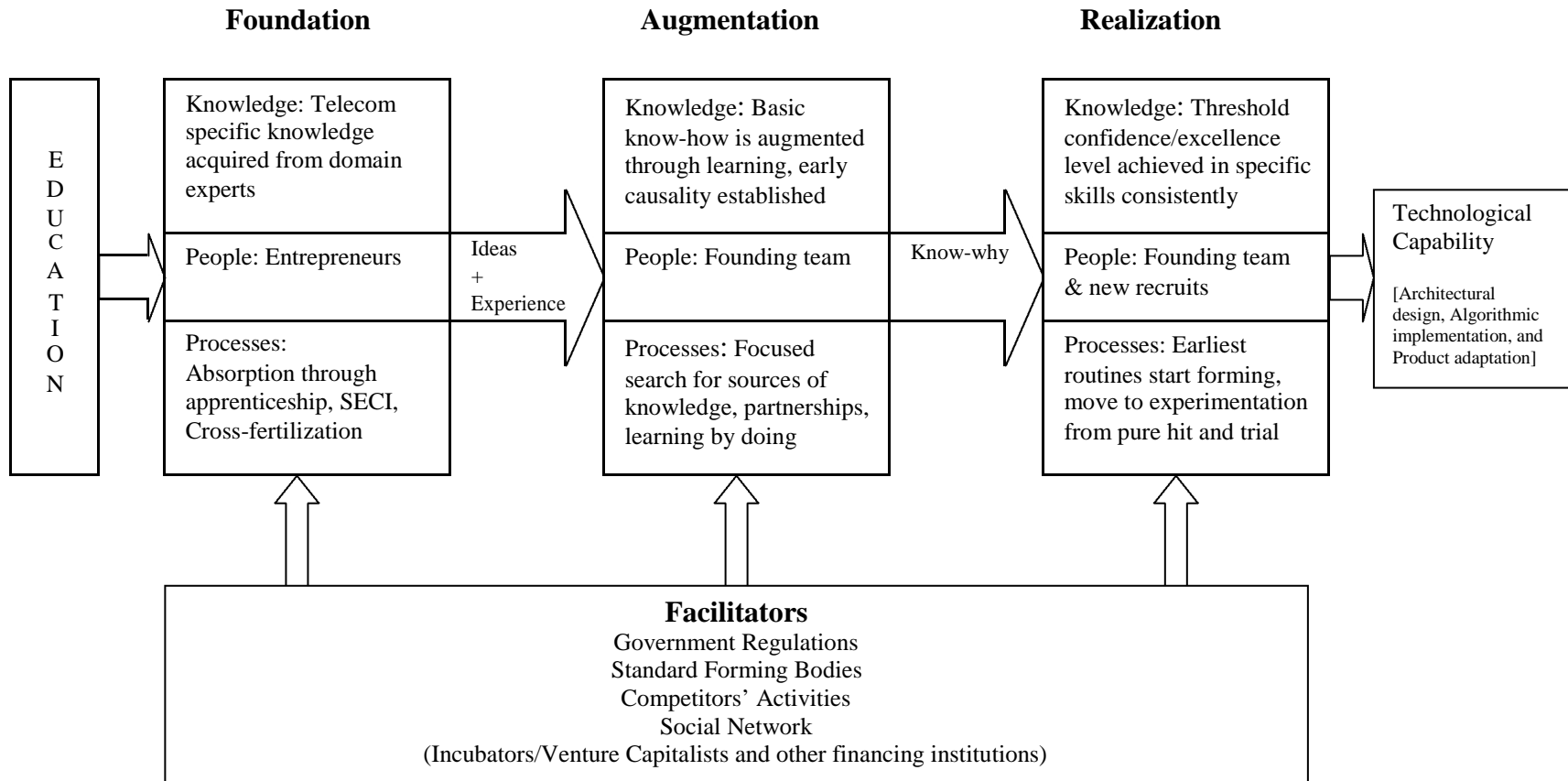All the above has been depicted in figure-2 on the page 24.

8. Conclusion:

Our work contributes to both theory and practice in many ways. Utilizing our three pronged criteria for identification we identify architectural design, algorithmic implementation and product adaptation as the components of technological capability among the telecom start-ups. Using our case firms as sample we present a framework for technological knowledge acquisition among the start-ups and the important role played by telecom specific technological knowledge in opportunity recognition. We also highlight the significant role played by prior work experience of the entrepreneurs. We further build on this acquisition of technological knowledge by linking it to capability lifecycle and extend existing theory by mapping the process of evolution of technological capability in a stage wise manner. We propose a three stage framework with foundation, augmentation and realization as the three stages and adaptive learning as the basic vehicle for maturation of an ad-hoc activity into a capability. Within this evolution process we presented evidence for the facilitating role played by social network, regulatory mechanism, standard making bodies as well as competitors in various ways.

For practitioners this work reiterates on the role of development experience and domain knowledge. Also the role of social network in enabling access to complementary assets and overcoming infrastructure related or other bottlenecks is significantly highlighted. Our work

also points to need for establishing exclusive centers for learning where telecom related technologies and skills can be imparted. Intuitively it seems that higher qualification in telecom could give a fillip to entrepreneurship in the sector as all entrepreneurs in our study were highly technically qualified although this proposition still needs statistical validation.

Through this work we have presented a snapshot of product based telecom start-ups and their evolution towards becoming commercially self-sustaining firms. An area of future research could be comparison of evolution charts of different organizational capabilities which could inform both theory and practice regarding the differences to be followed and peculiarities in the development of various organizational capabilities. Another interesting work could be interaction of different organizational capabilities and their impact on one another as well as on the firm performance. On a more broad level work on technology entrepreneurship in India is still in early stages and we hope our work motivates more work in this area.

Figure 2: Evolution of Technological Capabilities

Foundation   **Augmentation**   **Realization**

EDUCATION	Knowledge: Telecom specific knowledge acquired from domain experts	Ideas + Experience	Knowledge: Basic know-how is augmented through learning, early causality established	Know-why	Knowledge: Threshold confidence/excellence level achieved in specific skills consistently	Technological Capability [Architectural design, Algorithmic implementation, and Product adaptation]
	People: Entrepreneurs		People: Founding team		People: Founding team & new recruits	
	Processes: Absorption through apprenticeship, SECI, Cross-fertilization		Processes: Focused search for sources of knowledge, partnerships, learning by doing		Processes: Earliest routines start forming, move to experimentation from pure hit and trial	

Facilitators
Government Regulations
Standard Forming Bodies
Competitors' Activities
Social Network
(Incubators/Venture Capitalists and other financing institutions)

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