HUMAN CONSTRAINTS FOR MOBILE COMMUNICATIONS

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ABSTRACT

Mobile networks are proliferating currently in the world with a rather high pace. The number of mobile telecom subscribers has already exceeded one billion and the number will exceed two billions before the year 2010. The big investements needed in the telecom infrastructure raise the question, how much revenues can the operators and other players expect from the investments and what would limit them. It was shown earlier that the revenues obtained from human users of mobile networks and services are limited ultimately by the time the users are willing and able to use the services. In this paper we look closer at what are more concretely the limiting factors. The problematics is approached from five different points of views. First we analyse how much data is produced in the world in a time unit. This forms in a way the ultimate limit, because what does not exist cannot be transmitted. Second, the data volumes and types produced in organizations are analysed. This gives basis to estimate how much of the organizationally produced data could be transmitted over a mobile channel. Third, we analyze previous research that investigates how the people allocate their time among various activities, like sleep, work, watching TV, traveling to work or leisure activities, etc. Thus, only a fraction of the time of an individual can be used at the mobile channel. Fourth, cost models for communication capacity use and the key findings based on time users are willing to spend on communicating in private or work context are discussed. Last but not least, limits of human information processing from cognitive viewpoint are analyzed. Based on these

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different viewpoints we analyse their interdependencies and pinpoint questions that should be analysed further while determining the economic feasibility of the mobile networks.

1. INTRODUCTION

Expensive mobile communication equipment were used first for professional purposes, but consumers have fast followed business users in adopting mobile telephones, hand-held computers, and PDA equipment to daily use. The number of digital telecom handsets exceeds already one billion in the world. Borderlines between a laptop and mobile telecom terminal, as well as other gadgets, such as game consols, radio receivers, and TV sets are vanishing due to the ¨ miniaturization and digital convergence of information processing and communication technologies. At the networking side, extensive use of IP protocol in all device categories and within the core network, as specified by the 3rd Generation Partnership Project /19/ is a paramount example of convergence within networking.

The digital convergence has also mixed the usage patterns of voice telephone, data communication, and computer equipment making it harder for the operators to estimate the future use of communication capacity. This estimation task has to take into account the time users are willing to spend for network-mediated communication tasks, as well as the real communication needs and capabilities of the users.

We speak below about amount of information, but what we really have in mind is the volume of data the information is encoded into. Because the same information can have many different encoding, in fact an infinite number of them, measuring its volume through the encoded data is ambiguous, because a particular encoding has to be assumed, before we can speak about bytes. Below, the most commonly used encoding is assumed in the volume assessments, such as ASCII-characters for pure text, uncompressed format for telephone calls (with 64 kbps transmission capacity requirement), MPEG-2 for video, etc. Most volume estimates are given in bytes (octets).

This paper elaborates the estimation task of a telecom operator, by combining and analyzing the earlier research from the following five viewpoints:

First, we analyze the maximum amount of information produced and used globally by humanity, as estimated by the project "How much information" /2/ at Berkeley.

Second, we draw on measurements of organizational communication volume based on genre analysis reported in recent case studies. Based on these, we give a base-line for the average amount of data an employee communicates per day related to his/her assignments, whether using some technical channel or face-to-face. Employee's communication activity is divided into verbal communication, network-mediated interactive communication, and communication using usual paper or stored digital artifacts, such as digital documents or information systems.

Third, we analyze previous research that investigates how the people allocate their time among various activities, like sleep, work, watching TV, traveling to work or leisure activities, etc. This brings in a further limitation on the usage of a mobile channel.
Fourth, cost models for communication capacity use and their key findings based on time users are willing to spend on communicating in private or work context.

Last but not least, limits of human information processing from cognitive viewpoint are analyzed. This gives yet another aspect that sets limits for the human actor.

These five viewpoint are combined by analyzing their effects on interactive network-mediated communication of humans, limited mostly by the time spent by them to perform this task, and on the human communication using digital artifacts, constrained mainly by human data communication capacity. Further development is analyzed with respect of change of communication practices of organizations, and emergence of bandwidth intensive applications requiring high QoS and other emerging trends.

This paper is organized as follows. In section 2 we review the estimates for volumes of data produced by humans and machines globally. These estimates establish in a sense an ultimate limit for what can be communicated over networks, because only data that exists prior to sending can be transmitted. In section 3 we look into the organizational reality and the estimates for the volume of data produced in them by humans or machines. This gives a subset of data that is at least partially eligible for transmission over a computer or telecom network in the organizational context. In section 4 we look at human communication capabilities that also set limits for the network-mediated communication. In section 5 we combine the results and try to estimate how much of the produced data would be eligible to be transmitted over a communication network.

2. GLOBAL AMOUNT OF INFORMATION AND COMMUNICATION

It was estimated, that 1-2 exabytes (2’000’000’000’000’000’000 bytes) of new data was produced in year 1997/1/, corresponding to about 250 Megabytes per each human being. /2/. The data is mostly produced directly by people (typing it in) or its production has required real-time human control (photographs, videos) although the actual data has been produced by a device. The output of autonomously operating devices, such as satellites that produce a considerable amount of data every day, are excluded from the table.

Other estimates state that time needed to double the amount of information in the world has decreased from 50 years to 5 years, and the time needed to double documented (stored) information has reduced from 18 months even to 9 months /3,4/. Although these figures are typically very provocative presented by commercial consultancy organizations, at least the estimates produced by a research group at the University of Berkeley are coupled with the source data used. According to the project “How Much Information?” /2/ annual production of unique information (“original content”) consists of the following components (Table 1, figures extracted from Tables and text in Summary of /2/):

Table 1. Annual production of unique information in 1999. Figures extracted from Tables 1, 2, 3, and 5 of /2/.

Storage Medium / Content Type	Annual Terabytes Lower Estimate	Annual Terabytes Upper Estimate	Annual Amount of Titles / Millions
Office documents	19	195	7,500
Books, Newspapers etc.	4	45	1,1
Paper Total	**23**	**240**	
Photographs	41,000	410,000	80,000
Other Film	17,216	17,216	X-ray: 2,000
Film Total	**58,216**	**427,216**	
Music and Data CDs	9	61	0.091
DVDs	22	22	0,005
Optical Total	**31**	**83**	
Camcorder Tape	300,000	300,000	1,400
PC Disk Drives	7,660	766,000	110
Servers	269,550	627,000	90
Magnetic Total	**577,210**	**1,693,000**	
TOTAL STORED	**635,480**	**2,120,539**	
Computer-Mediated			
Email	11,285		610,000
Usenet	73		HTML 2.1 Usenet 6
TOTAL C-MEDIATED	**11,358**		
Analog Communication			
Radio and TV	14,938		
Telephone	576,000		
Postal	150,000		
TOTAL ANALOG	740,938		

The underlying assumptions in this research have been that all data – including print media – is estimated in bytes (octets). The large figures are obtained by assuming a verbose encoding for the information, such as RGB encoding for images and video, whereas the minimum figures are assuming a "reasonable compression" (JPEG, MPEG, etc.).

From table 1 we can see that when measuring by bytes of unique data, the total amount of stored data was round 0,7 to 2,1 Exabytes, i.e. 700,000 to 2,100,000 Terabytes. Most of new data was produced by individuals recording home videos or individual computer users (0,6 to 1.7 Exabytes on magnetic media). But also telephone calls amounted close to the same volume, 0.576 Exabytes. This estimate was based on ITU estimate of $2.5 * 10^{12}$ minutes per year for 207 countries extrapolated to $7.5 * 10^{12}$ minutes per year, or roughly 600,000 terabytes per month (with compression factor of 6 to 8). The ITU estimate would mean for the population of 7 billion individuals on earth that every one of them spoke ca. 360 min/year at phone. Subtracting those who are too young, too old, or too poor to be able to use a phone, ca. 2/3 of the population, the rest of the population would spend about 1100 min/year by speaking at phone in average. Assuming for the above voice stream no compression, and take into consideration that the connections are duplex, this would mean 960 kB/min data, i.e. $2.4 * 10^{18}$ bytes uncompressed voice data in a year.

In case we use unique titles as the measurement units, the largest category was photographs with 80 billion images and the second one was office documents with 7,5 billion titles accounting for 81% of all the printed material produced in the world. However, according to Davidson Consulting referred in /2/ about 400 billion pages per year are faxed annually (corresponding about 6,000 terabytes of fax data per year).

It is worth of noticing that the above figures do not contain all data that was produced by autonomously operating machines, like satellites, terrestrial sensor networks (fire alarms, readings of electricity meters, elevators, vending machines, industrial process plants), car, aircraft or vessel control processors, etc. Some condensed excerpts of the information produced by these systems is presented at some point to humans. Most of this data could be transmitted wirelessly, and some can only be transmitted wirelessly. This has opened a new business area sometimes called Machine-to-Machine business (M2M). We do not treat in this context M2M area further, but want to just remind that is an area that produces more and more data every year, as more and more of analog control systems are replaced by digital ones and the number of various sensors and digital control units increases.

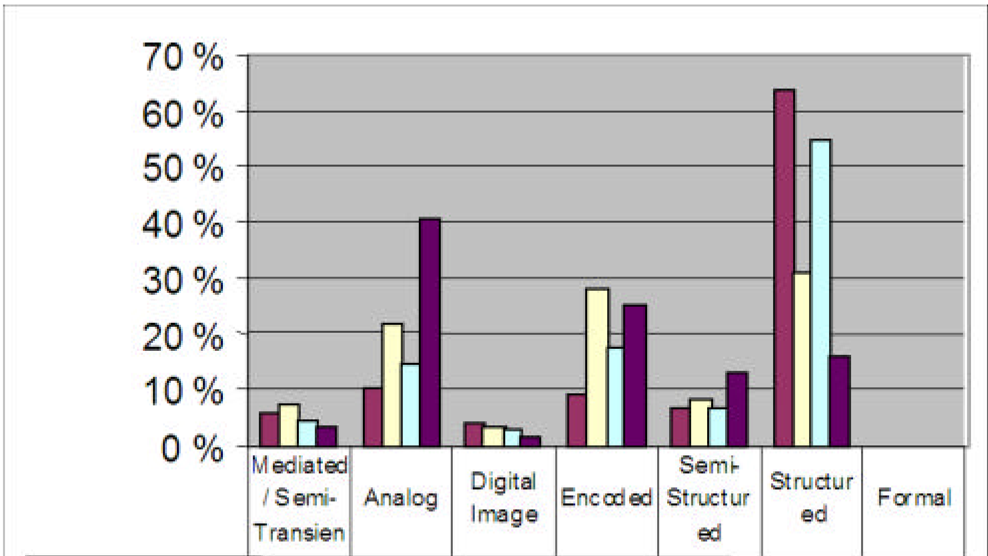
3. INFORMATION AND COMMUNICATION IN ENTERPISES

Professional users in enterprises have been the primary target group for new information and communication technology due to their capability to adopt and invest on ICT equipment and services /10/. The adoption of new technology and services is easiest when the technology matches an existing need for communication /10/. From this viewpoint it is beneficial to analyze the communication in organizations and estimate the potential of new technology with respect to the analysis results.

A recent case study performed in a high-tech organization /5/ estimated each employee of the organization to communicate about a hundred pages (92 pages) of information on an average working day. "A Page" was used as the measurement unit in order to unify the quantities of verbal communication, communication on paper, telephone calls and other ICT-mediated communication as well as communication using stored digital artifacts, such as digital documents and database records. Most of the communication was information received or forwarded while less than ten percent was newly created information sent or communicated to one or more receivers. Figure 1 represents the distribution of the communication according to four measures used in /5/ for each of the seven categories of mediated communication (see Figure 2).

In Figure 1, the category Mediated/Semi transient refers to telephone calls and videoconferencing mediated through ICT, Analog refers to paper, VHS video etc., Digital image refers to faxes and bitmap images, Encoded refers to e-mail, office documents and other ASCII-based media, Semi-Structured refers to Lotus Notes applications and other combinations of metadata fields and encoded / bitmap data, Structured refers to XML messages and other data represented as tables, forms and other documents, and Formal refers to database information intended primarily for computer use. Figure describes the taxonomy of categories by graphical inclusion of the categories in their super-categories (adopted from /5/).

Annual UI refers to number of **U**nique communication **I**nstances, such as number of unique e-mails sent or received by the members of the organization in a year. Annual UI Volume refers to the volume of the content in previous, when measured in "Pages", i.e. displayed content. Annual Copies and Annual Volume refer to the same figures, when including also the copies of, e.g. mail messages in the numbers and in the Pages. The figure 92 pages per person day refers to the last figures, in which about 40% of the communication goes through paper and other analog media. But this seems to be mostly due to large number of copies of paper documents – if the copies are excluded, most of the unique information is communicated using semi-structured (31%) and encoded (28%) media, paper being the third with 22% of the total volume. Another case study in an university faculty results also in the same order of magnitude /6/.



	Mediated / Semi-Transien	Analog	Digital Image	Encoded	Semi-Structured	Structured	Formal
Annual UI	6 %	10 %	4 %	9 %	7 %	64 %	0 %
Annual UI Volume	7 %	22 %	4 %	28 %	8 %	31 %	0 %
Annual Copies	4 %	15 %	3 %	17 %	6 %	54 %	0 %
Annual Volume	4 %	41 %	2 %	25 %	13 %	16 %	0 %

Figure 1. Distribution of communication forms in an enterprise for communication using medium (adopted from/5/).

From our viewpoint, the distribution of communication presented in the first study is of most interest (see figure 1). When observing the total amount of communication (Annual Volume), the category Mediated/Semi-Transient communication form only 4 % of all the communication that uses some medium. The category Digital Images corresponds to fax and other bitmap images, that could be delivered using multimedia messaging (MMS), covers only about 2 % of the communication volume. Instead, the Encoded communication forms (corresponding to ASCII text in mail messages and office documents) accounted for 25 % of the volume. Further, Semi-Structured and Structured communication forms (matching with

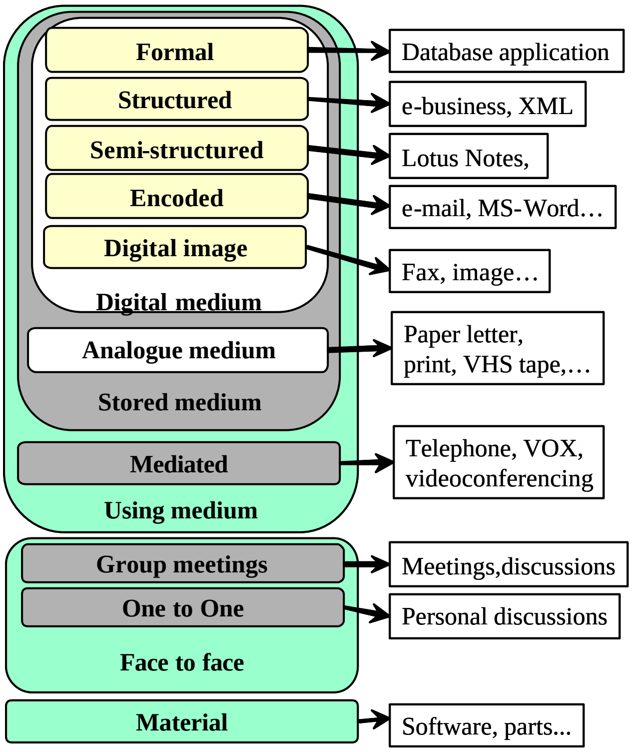


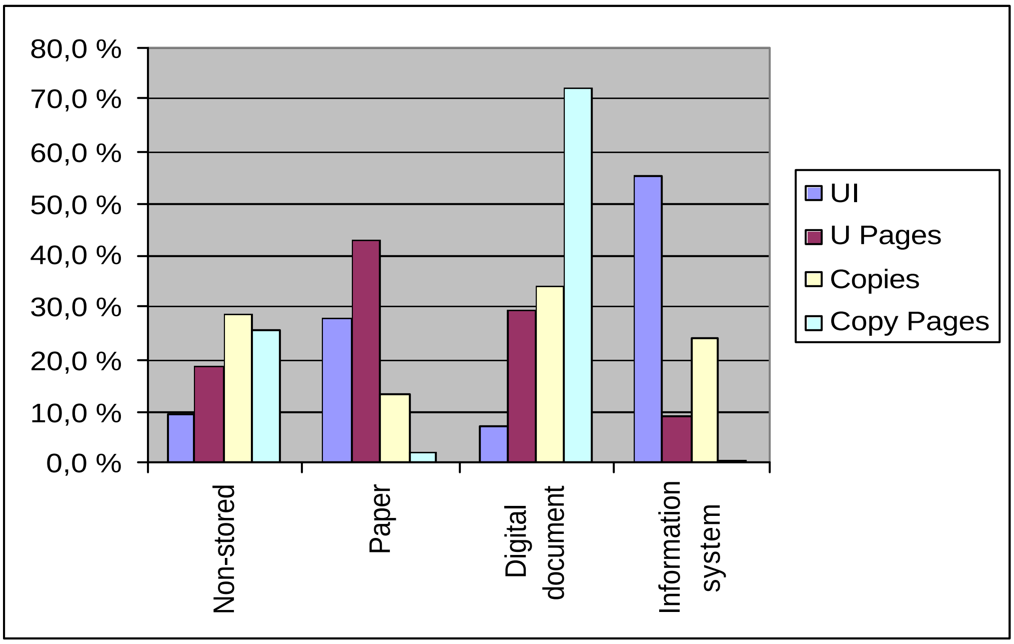
Figure 2. Taxonomy of the categories of communication forms (adopted from/5/).

XML, Lotus Notes applications and alike) form together almost 30 % of the volume. The rest of stored communication (41 %) was mediated using paper and other analog media

Both this first case study and the second case study at the university faculty reported the proportion of paper communication going down rapidly. This implies that the new demand for ICT services will be driven from the technology applicable for replacing paper medium. The second study reported that communication on paper was a minor portion when measured with the number of communication actions and unique data, but was by far the largest communication form when measured by communication volume (see Figure 3). This seems contradictory at first glance, but is easily explained by the fact that the unique information on a sheet of paper is often copied to many people; in the case of course material the number of recipients might be hundreds of students.

Assuming that the unit "Page" correlates with the amount of bytes to be communicated, this implies that the introduction of larger documents will also require more communication band-with to be offered both by the internal network infrastructure and by the inter-organizational infrastructure than the previous digitization phases in organizations. This is because in earlier phases mostly text encoded with 7- or 8-bit ASCII was used, whereas now XML-encoded documents, as well as image, audio, and video data are in use.

Transferring digital documents (that replace the paper documents) should require relatively limited band-with, if compared with video transmissions. Talking about videoconferences, they primarily replace face-to-face meetings and thus save peoples time and money that was spent while traveling and taking part in the meetings. A video conference can hardly replace distribution of digital documents, and hardly any document exchanges can replace a videoconference: During March-June 2003, when China and other Asian countries were hit by SARS, companies used a lot of video conferences as a replacement of face-to-face meetings, that would have required travel to/from SARS infected countries. The exchange of information was based on emails, phone calls, faxes and other digitally encoded/formal documents, because these do not carry human viruses, unlike, perhaps, paper documents and



because these are necessary as meeting material. During thethreat posed by SARS, companies having cooperation with SARS-infected countries increased their usage of networking infrastructure /11/.

Figure 3. Distribution of communication in the university case study (adopted from [6]).Here the category “Non-stored” refers to all categories from material to mediated communication, “Paper” refers to analog communication media, “Digital document” refers to digital images, and encoded categories, and “Information systems” refers to the categories from semi-structured to formal communication forms.

Apart from special situations, like the SARS epidemic, the results from the Berkeley study /2/ referred to earlier suggest that video streaming will overwhelm digital document transmissions in volume also in enterprises. The reasons can only be guessed. Anyhow, the traffic patterns of delivering multi-megabyte documents (video clips or other massive documents) on demand from centralized document storages will probably have some impact on network optimization and charges. If the video streams are assumed to be played at the same time as delivered from the servers, end-to-end streaming guarantees should be provided by all the networks on the path from the server to the (mobile) client.

Analysing the results in this section one can draw the following conclusions. First, any digitally encoded data is eligible to be communicated over a network. For simplicity, we view all mediated and semi-transient communication, including analog voice and video streams as digital in this context and consider them to be eligible for transmission over a digital network (which also happens in reality within the modern telecom backbone networks).

All digitally stored contents is also eligible for digital transmission over a network. There are, however, characteristics that make some contents impractical to be transmitted on certain kinds of networks. Typically, large volume-data cannot be reasonably transmitted over mobile networks due to low transmission capacity of the air interface (1 kB/s –30 kB/s) and simultaneous high transmission costs. Second, streamed data (voice, video) does not always exhibit the required QoS parameter values on packet networks, such is IP networks. This problem can always be alleviated, however, if the receiving end has enough memory to store the whole stream or most of it before starting its presentation, in which case there is no missing data.

It is worth of noticing that even if the humans working in an organization would process (produce+view) about hundred pages information, this does not directly determine how much data is communicated within the corporate network or over the organizational border. This is first, because there is face- to-face communication that is not technically mediated.
Second, there are paper documents that are not sent outside the corporate boundaries. In a modern corporation, however, almost all documents are produced by computer tool (word processors, spread sheet programs, databases, etc.) and printing is often done using network printers, so at least at some point of time the document is transmitted over the corporate network, even if it appears on paper (see e.g. [6]). Thus, any recently produced document has also a digital representation making it eligible for digital transmission. And older documents can be transformed into digital ones by scanning them into images (fax or other format). So,

one can argue that for most paper documents there is a digital counterpart. It is worth of noticing that in some industries where the life span of a product is very long, even hundred years, more engineering documentation exists in paper format. Typical examples are paper mills and power plants. This material is partially sanned into digital formats, but not entirely.

Third, once an employee has produced a document and stored into a digital format, it can be transmitted over networks infinitely many times. A typical example is the main WWW page of a company that, once created, can be accessed a million times a day and transferred for each access to a different client. Thus, if a company has 10 employees that can collectively deal with 1000 pages a day, over the network access point of the company 1000 times more pages are transmitted to external agents.

The same also holds in the opposite direction, the external agents can transmit more pages to the company over the network access point than the individuals employed by the company can handle, as long as the computer systems receiving the pages can handle them automatically. This is the idea if EDI and later that of various forms of E-commerce. Of course, nothing is gained if the computer system only stores the requests and a person has to process them, but if the computer can satisfy user's request without human intervention, personnel can be saved. A typical example is Internet banking. The customer interacts with the computer system of the bank and does his or her banking transaction without any need for human intervention from the side of the bank. This has lead to a huge increase in the network traffic towards the bank servers and reduction of the personnel. For instance Nordea bank /9/ can be accessed from anywhere in the world over Internet and all conceivable banking transactions performed.

In order to implement this change of operational practices, the contents has to be defined in a format that the programs can "understand", i.e. with communication forms at the upper levels of the taxonomy (formal or structured communication forms) in Figure 2.. Using these highly structured formats improves process throughput even when humans operate the processes. For example, we have observed an organization processing orders with database applications, where the average amount of information manipulated per person exceeds 200 pages per day.

4. HUMAN LIMITS AND WILLINGNESS TO USE TIME FOR COMMUNICATION

Landauer estimates, that humans take in and remember about a byte in a second, i.e. up to 675 KBytes or about 300 Pages during office hours/7/. When compared with the previous sources /5,6/it seems as if the persons in the target organizations would spend about a third of their time in communicating.

Aarnio et al /8/ observed, that the early adopters of new mobile services are the ones, whose bill the employer will pay. In case of leisure time, both the real cost of communication and the competition over the discretionary time of an individual impact the use of communication networks.. On an average, an adult in USA has about forty hours of discretionary time per week to spend with television, radio, other media and other hobbies competing on the user time /12, p.339/. When comparing the statistics on media use, the time spent on various media exceeds the discretionary time /13/.. E.g. talking on a mobile phone while reading a newspaper and having the TV on - or talking/listening to radio while driving – will impact these figures as more than one media are followed simultaneously. These phenomena can be observed in Tokyo, where especially young people are walking on the street or traveling in the bus or subway and use their mobile phones to access I-mode and other mobile services at the same time. If they are on their way to work or home, this is not necessarily discretionary time, but neither is it working time – or it can be both. In Japan, one talks about "niche time" that is used to access mobile internet services. These might be accessed either in order to perform some work-related activity or some private activity.

This new usage of time raises the question, whether there is a need to look closer into the principles used in time usage studies and perhaps adapt them to the new situations, where media is used simultaneously with other activities and in places where earlier only waiting and perhaps reading newspaper was possible. Looking closer at the time categorization used in /13/, as described in detail in /14/, one sees that indeed, mobile phones and mobile Internet usage is difficult to place under the about hundred categories used in /13/. .

How much time the users are willing to invest in mobile communications, if the employer pays the communication costs? Our hypothesis is that from employee's point of view it is the time consumed to achieve something useful that is crucial in this case. From employers point of view the benefit of using employees' time at the mobile channel should be larger than the cost caused by this time usage.

Majority of this channel usage cost comes from the salary costs of the employee while current mobile channel costs are secondary (e.g. 30-60 $ per person hour compared with 20-30 $ for the communication channel). Thus one could expect enterprises to encourage use of mobile communication devices, when possible. Further, doubling the communication band-with may cut the personnel costs half encouraging operators to have aggressive pricing for high capacity connections and QoS.

However, personnel costs are relatively easy to estimate and budget in advance while high communication costs are one of the first places to save when budgets are tight. Further, in many occasions it is difficult to quantify the savings or benefits of using the mobile devices. From the individual point of view, the situation is basically the same, but the question is: does the value of the service I am using warrant the time and money I am investing into it? The "value" for individual usage is more complicated to evaluate than for the professional usage. What is the value of playing a game on a mobile handset? For one user it might be a high pleasure, and thus of "high value", for another playing the same game would be pure waste of time and money. Thus we end up with using personal justification of the device user as the base-line in most cases, i.e. end up with using the percentages of time one is willing to spend on communicating as the limiting factor. This was elaborated in a more detailed way in /16/. What was not explicitly addressed there was the fact that the conditions and preferences in professional and personal use are different. This deserver more attention. As such the fact that mobile channel is one among several other channels that compete about the users time is worth of pursuing further.

A question that deserves attention in the professional context is what happens if the employee is working outside the corporate premises, as concerns the network usage and information needs. Does the employee process less information than average? Does his or her needs to communicate with the colleagues or the corporate servers increase or decrease - or remain constant? This is certainly largely dependent on the particular work the person is doing. A recent survey in Japan among the early adopters of Mobile Internet services revealed that maintenance personnel of NEC going to customer premises has used for long time mobile phones to be in contact with the company office. They inform the managers of problems, get advice and new work orders by phone. However, using applications to transmit the data over mobile data connections has reduced considerably the time maintenance personnel has been talking over phone and has reduced communication costs by 100 million Yen/year. Further, recording the problem description obtained from the customer and playing it to the maintenance engineer on the phone has reduced considerably errors and misinterpretations done by human operators while receiving the problem report from the customer at the call center and writing it down. /10/. The information is sent to the engineer by mail that contains URL:s from which the details can be fetched.

Yet another aspect having major impact on communication needs is the organization of work. In case work break-down is planned to minimize inter-group communication, the requirements for communication capacity may be reduced drastically compared with ad-hoc task assignment distributing persons or organizations interacting heavily with each other to geographically separate premises and locations. Typical limit for natural face-to-face communication is approximately a distance of 15-20 meters. Beyond that the use of phone, e-mail and other mediated communication channels will increase fast. Further, time zone distance above 8 hours will turn most of the communication from interactive phone discussions to e-mail and other mediated communication.

In distributed organizations the stored communication through digital documents tends to increase the size of the documents as well as the number of copies distributed when compared with paper documents. This is also visible in Figure 3, where the digital documents form less than 10% of the unique communication actions, but about 30% of both the volume of unique communication and of the number of copies. In case this kind of non-interactive communication is taken care of by centralized repositories rather than by broadcasting all the documents, the communicated volume will drop. The use of storage sites for MMS messages and integration with corporate systems can reduce the load potentially caused by, for example, distributing multiple copies of MMS messages for delivering a fax or a paper scanned or photographed at one site. The need for spending effort on this kind of arrangements depends partially on the pricing of the communication channel compared with the cost of making the arrangements for efficient information delivery and work break-down structure.

5. CONCLUSIONS AND DISCUSSION

Drawing together the findings above, we can perceive the situation as one where most factors limit the usage of the mobile channel by a person. Let us first divide the information into two categories, such that is produced and consumed simultaneously (transient information, TI) and to such that is stored into the network for an indefinite time and transmitted to person or machine later any number of times (persistent information, PI). The voice and video calls belong to the first category, books, database contents, stored video clips etc. to the latter.

Looking at the restrictions, first, of course only such information that is digitally encoded can be transmitted and manipulated on mobile channels and devices we are interested here. Currently, most of the digital information flowing through mobile networks (air interface) is voice (TI). In the most developed countries, like Japan, the voice traffic volume per subscriber does not grow any more, but it is rather slightly decreasing /18/. Only mobile data traffic volume is growing, both absolutely and per subscriber. The main reason for this are mobile internet services, like i-mode.

Voice streams generated by a human at one terminal and consumed by another at another terminal are of course eligible for mobile digital data transfer and usage. But there is digital transient or persistent information that is not eligible to be transferred through any mobile channel, or through too slow or insecure mobile channel. Orthogonal to that, not alldigital information can be handled on mobile devices or on a particular mobile device. Thus, there is digital information that is excluded from mobile usage. Typically, security or privacy reasons might prohibit transfer of certain piece of information through a mobile channel to/from a mobile device (private key).

The remaining information is typically too bulky to be transferred and manipulated in the mobile environment, or its encoding is not supported by mobile devices.. If we denote by $B(PI\_{_1})$ the number of bytes stored at a certain moment T1 and by $B(PI\_{_2})$ the number of bytes stored, say a couple of years later, we can argue,

1) $B(PI\_{_1}) < B(PI\_{_2})$ This is simply because humanity produces more stored data than discards it during any time interval since the invention of digital technology.
2) A larger number of documents in $PI\_{_2}$ are eligible for transmission and usage in the mobile environment than in $PI\_{_1}$ This claim can be made backed by several arguments. First, the memory and processor capacity, as well as data transmission speed of the mobile devices is rapidly increasing and they have also become programmable. Thus, data encoded in various formats meant for PC or other environments becomes usable in these environments. Second, the mobile industry is creating more and more contents

in formats designed for mobile environments, such as XHTML, MPEG-4, SVG.¨, etc. Third, the core networks and air interfaces are becoming faster with 2.5G and 3G deployment. Thus, it becomes practical to transfer larger documents than before over wireless networks, because transfer time and cost are reasonable.

An interesting question that requires further study is the following: does the percentage of the bytes in PI eligible for mobile environments grow, shrink or stay constant over time? That is, which one grows faster, the data contents eligible for mobile environment or that for other environments? Another related question is what is the corresponding ratio among the documents. These two measures might be rather different, because voluminous documents not eligible for mobile usage might dominate the byte count, but the the small documents eligible for mobile usage might still dominate the document count.

In any case, the above-mentioned persistent data eligible for mobile usage has potential to grow. But not limitlessly. As was discussed in /16/, the time the user is willing to spend at the mobile channel and devices is a crucial limit. In the light of the above discussion it is meaningful to distinguish between the time the user is producing mobile data (or contents) and the time he/she is consuming contents at a mobile terminal. For a voice or video call the contents is produced and consumed instantaneously and usually the contents is not stored (TI). In most cases two persons spend the same time using the terminal. The operator revenues are generated during this time, i.e. either caller, or the called, or both pay. As was discussed above, the average number of minutes spend in this way by people who are able to do it was roughly 10 hours/year. Some hours of this are used at the mobile channel. In Japan and Scandinavia there are a lot of people who do only have a mobile phone, so all revenues generated by these people are collected by mobile operators. As was said above and in /16/, the time a person wants to talk at phone per month is most often restricted by the time he or she has for it in the personal time budget, not so much by the cost. In the business environment, as was discussed above, the money is even less an issue and the decision when and how much to use the mobile phone is determined more from working time efficiency aspects. There is a need to do further analysis on these aspects.

The mobile services other than voice calls require time to consume them. In this case, again the time budget is important. As was said above, business use differs evidently from personal use, because the value metrics are different. The leisure time use and working time use of mobile services is thus most probably deemed differently by individuals and organisations. This should be investigated further.

The current mobile environment offers possibilities also to produce digital contents using the terminal other than voice. The popular forms are short messages in Europe and emails in Japan. The newest terminal generations also support digital images and even video clips (on June 24th, 2003, a video clip taken by a mobile phone was shown in main news of NHK from a severe traffic accident on a highway in Japan). This opens up new possibilities, but one still asks, who would be willing to invest his or her time to produce contents for free. Another thing is, who would like to invest his or her time to watch the contents? Where would this time be taken from? Consider that a person has 10 friends each of whom take a video clip of one minute once a week and send it to the others. Producing the video clip would require 1 minute per week time, but watching all the contents produced by the group would require ten minutes per week from each of them. And mobile operators would get 100 euro/week from the group for transmitting the clips 1 €/piece?

Again, for professional content production the thinking is perhaps different. If the contents must indeed be produced while on the move, then production should be efficient and the terminal user interface and other capabilities correspondingly good. These aspects should also be investigated further.

Finally, as was discussed above, a human being has a certain capacity to process information (byte/second). Basically, the overall human information processing capacity in a time interval T is proportional to S, where S is the length of the interval T in seconds.. This forms an upper limit for the processing. Thus, the time the user is willing to spend in consuming the contents and the processing capacity of a human being.

When we compare the technology enablers and user requirements of mobile communication channel use, some generic trends can be observed. Along with increased capacity and diverse means, the main limitations of use are gradually shifting from technological barriers to the users willingness to use the technology. From the this perspective, the main constraint of business users is efficiency in the usage of working time, while the individual users are limited strongly by both by time usable at the mobile channel and costs levied on services.

The use of private video material of individual customers is the largest single source of new mobile data. Following the business users of high-capacity networks, the individuals sharing their video content will consume any cost-free or low-cost band-with available. One of the major questions is, to what extent this communication is interactive, attention catching activity requiring high QoS vs. to what extent it can be supported with low-cost left-over capacity.

The time budget of a person has typically been divided into work time and discretionary time. In addition, the new nice time needs to be considered when usage of communication is considered. In all of these three time-slices, the attention of an user is focused on a single channel. Secondary channels may compete on the attention, e.g. headlines of radio or TV news may catch the attention while talking, reading or driving, but only occasionally. A third category of m-to-m devices is emerging. The first category (attention) is extremely time-limited, while the second and third categories are used in parallel with other communication channels, with costless or extremely low cost connections. For business users, the later two categories are rather irrelevant.

In business, often at least a third of the time is spent on communicating. With stored media, most of this is receiving information on some stored format, e.g. reading digital documents. In verbal communication the proportion of sent information is higher, up to half in one-to-one communication. Traditionally, organizations have minimized communication requirements through organizing work and by relocating people. With the increased pace of re-structuring, the portion of verbal communication between geographically distributed members of virtual teams is increasing. This has also a major impact on the bandwidth usage accelerated by the relatively high band-with requirements of videoconferencing and technology-supported collaboration tools supplementing verbal communications.

We have above discussed human-related limits for mobile environments. These limitations induce correspondingly ceilings in the revenues of operators. How the limits exactly could be estimated is for further study. We would like to remind the reader also of the fact that not only mobile human-human and human-machine communication produce revenues for the mobile oprators, but also machine-machine communication. The revenues generated by this traffic are not directly limited by restrictions found to be valid for human beings. We anticipate that M2M communication volumes are limited more directly by economic feasibility, i.e.

cost/benefit relationship. It is still worth of asking, whether some human-to-human or human-to-machine communication can be replaced by M2M communications. Typical scenarios where this could happen are e.g. automatic failure diagnostics of car engines, or other moving or autonomous machines. This is also for further study.

6.QUESTIONS FOR FUTURE RESEARCH

We compile the open questions discussed earlier into a list:

- how much data can be generated by humans and machines
- how much data a human being is able to digest in a time unit, such as a day
- how much of the produced data is transmitted through a digital communication channel
- how much of legacy information stored in paper and other analog media is needed for further use and is scanned as bitmaps or similar medium requiring large band-with
- how much of the above data is eligible for transmission over a wireless link taking into consideration the transmission capacity of the link and the time the user is ready to wait for the transmission and company or user to pay for the transmission.
- How much of the above data can be reasonably handled at a mobile terminal
- how much costs are caused as compared to the benefit of using the mobile channel in a particular situation
- what are the differences in valuating the mobile services and time used at them in personal use (during leisure time) and professional use (during paid working time)
- to what extent are the persons able to conduct face-to-face meetings instead of having distributed organizations in multiple premises
- to what extent has the work performed by an organization been broken down into a structure, where the need for communication is minimized across persons and groups located apart from each other
- how much time are the users able and willing to spend at mobile channel during their leisure time and working time and what sets limits for this

- how should the “niche time” usage of the mobile terminals and networks be related with earlier time usage research
- What sets limits for the mobile M2M communication volume
- How does increasing M2M communication influence the human-to-human and human-to-machine communication?

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