i-mode: wireless service *à la* Japanese

Ludovic COPÉRÉ – `ludovic@kth.se`

3rd June 2004

1 Introduction

Faster, fuller and cuter. This is a short but good way of summarizing mobile phones in Japan. The rich mix of advanced technology, the burgeoning mobile content sector, and a high rate of citizen cellular penetration[1] give the country the essential ingredients for developing innovative services on top of the existing infrastructures.

The key player in this field is NTT DoCoMo[2]: with 64% of the market share for cellular subscriptions, it is the undisputed leader. It owes this results partly thanks to the gaudy yellow "i" button tens of million of users are casually pressing everyday: the i-mode service. Sometimes nicknamed the "Japanese WAP", it is in fact extremely different in its technical and business processes. This report outlines the major characteristics of i-mode and shows the main reasons for its success.

2 Architecture and Technology

2.1 Cellular technologies in Japan

Some of the unique characteristics of i-mode come from the distinct cellular technologies in use in Japan. It is therefore necessary to briefly summarize the state of the cellular system in use in Japan.

2.1.1 Low Tier: Personal Handy-phone System - PHS

Using the terminology found in [Mag04], Japan has both low tier and high tier cellular systems in use. The low tier system is PHS, Personal Handy-phone System. From its launch in July 1995, it has been aimed and marketed at providing an alternative to full-fledged cellular phones, with the former being cheaper and lighter than the later, while being more convenient and usable than a paging system: an ideal infrastructure for low-mobile and low-power wireless applications.

PHS is a microcellular digital cordless telephone system that can be used in both outdoor and indoor environments, in a public (connection with the PSTN networks) or a private context (home or small-office internal cordless system). As detailed in [IKYI97], PHS has the following main technical characteristics, shown in Table 1.

The main enhancement brought by PHS over competing cordless systems, such as DECT (Digital European Cordless Communication) and CT-2 (Cordless Telecommunication-2) is "intelligent" network management. Indeed, [IKYI96] shows that there is a clear separation between the access itself, the service switching, control and management, thus allowing scalable use and deployment on a national scale.

[1] More than 86 million cellular subscribers out of a population of 130 million, among which 72.5% are Internet-ready, according to [Ish04].

[2] `http://www.nttdocomo.co.jp/english/`

Characteristics	Value
Frequency band	1895.0 – 1918.1 MHz
Radio Coding	TDMA-TDD
Channels / carrier	4
Coverage	50–100m (indoor), 100–400m (outdoor)
Voice rate	32 kbit/s ADPCM
Data rate	384kbit/s
Power	10mW
Velocity	Walking

Table 1: PHS characteristics.

2.1.2 High Tier: Personal Digital Cellular - PDC

Japan's second generation high tier cellular system, PDC (Personal Digital Cellular) has been developed by NTT DoCoMo and launched in March 1993, as a replacement of the earlier, first generation, analog network. It has the following characteristics, as shown in Table 2:

Characteristics	Value
Frequency band	810/940 MHz, 1.4 GHz
Radio Coding	TDMA
Channels / carrier	6 half-rate / 3 full-rate
Coverage	1.5–10km
Voice rate	11.2kbit/s
Data rate	2.4–9.6kbit/s
Power	0.6–1.0W
Velocity	High speed

Table 2: PDC characteristics.

It should be noted that PDC is, by far, the most spectrally efficient TDMA system in use: where IS-136 has 3 channels in a 30KHz frequency space and GSM 8 channels in a 200KHz frequency space, PDC manages to have 6 half-rate (or 3 full-rate) channels in a 25KHz space. Throughout the years, it has also evolved by using spread-spectrum technologies, which push the limit to 131 channels in a 1250kHz band. Thus, it even compares fairly well with other CDMA systems.

To achieve such high spectrum efficiency, the network architecture as been designed as shown in Figure 1.

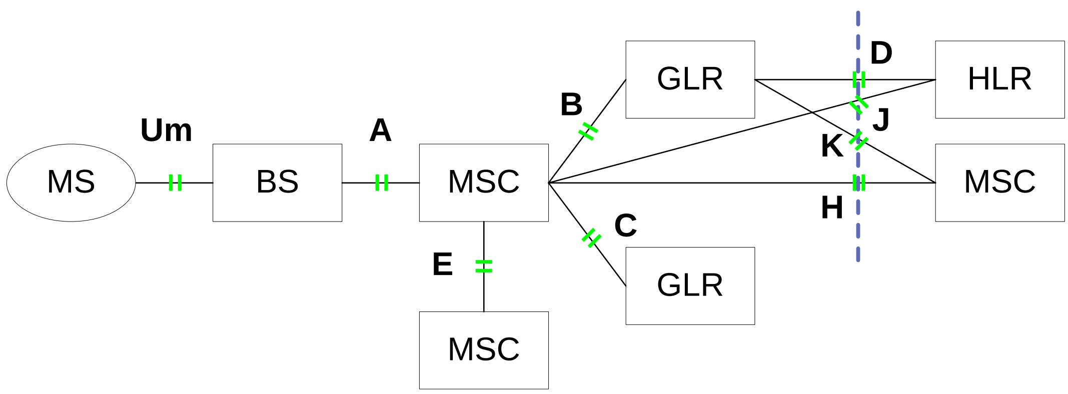

Figure 1: PDC Network Architecture.

The main elements of the network are:

- MS: Mobile Station.
- BS: Base Station.
- MSC: Mobile Service switching Center.
- HLR: Home Location Register.
- GLR: Gate Location Register.

The standardization of PDC provides 9 interfaces to be implemented:

- Um is the mobile user-network interface.
- Interfaces B, C, D, E, J, K and H are defined and deployed by the cellular carriers (such as NTT DoCoMo and KDDI).
- Interface A is free for being implemented by each provider.

Further details on PDC and its internal switching and messaging processes are given in [TNY93].

2.1.3 PDC mobile Packet Data Communication - PDC-P

As a 2G cellular system, PDC is based on circuit-switching for providing voice and data services: the accounting and billing is time-based, which is not optimal for data exchange and transfer. That is why NTT DoCoMo launched PDC mobile Packet Data Communication (PDC-P) in March 1997, to provide a packet-based communication service on top of the existing PDC network[3].

Indeed, as underlined in [MMOH97], the authentication, mobility, and roaming systems can be shared between PDC and PDC-P, the later implementing the following services:

- Packet-based transfer at high speed: definition of a new packet physical channel, which can deliver rates up to 42kbit/s, using the 3 TDMA channels of PDC (*i.e.* a maximum theoretical transfer rate of 14kbit/s/channel, and an actual usable maximum of 10kbit/s/channel, according to [HNU95]).
- Compatibility with different network protocols: PDC-P was originally based on TCP/IP as the "standard" suit of network and transport protocol to interconnect with the Internet. However, the lower layers of PDC-P are independent of this choice, and other protocols, such as X25 and AppleTalk, can be used (although the current infrastructure does not actually use them).
- Inter-operability with PDC: PDC defines a paging channel for voice communication that the MS monitors for incoming calls. PDC-P extends it to monitor incoming packet transmission. In addition to that, PDC-P takes advantage of the handover and encryption features already present in PDC.

A summary of the PDC/PDC-P architecture is shown in Figure 2. The main components of the PDC-P network are:

- PPM: Packet Processing Module. It receives and sends the packets from and to MS, through their associated BS. The PPM is also connected to the VMSC (Visited Mobile Switching Center) to signal to the MS whether to expect a data packet or an incoming voice connection attempt.
- M-PGW: Message Packet GateWay module. This is the interface towards various external networks, such as Internet and provider's LANs. It communicates with the PPM to deliver the packets to the MS.
- P-MDE: Packet Modulator/Demodulator Equipment. This is the physical layer that provides compatibility with the PDC electronics in the MS.

Further details about PDC-P and its associated packet data communication control can be found in [MMOH97].

[3] It is similar in its scope to what CDPD brought to AMPS in the USA and what GPRS has brought to GSM.

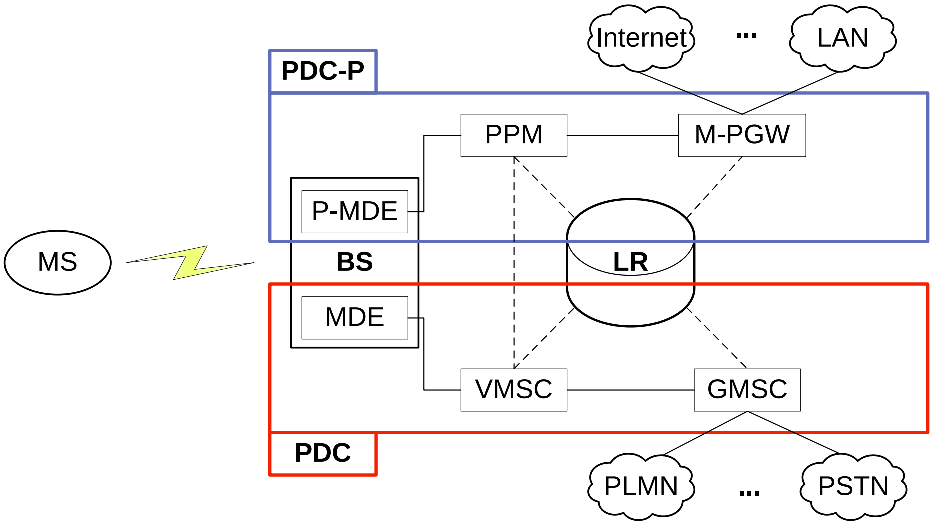

Figure 2: PDC-P architecture.

2.2 i-mode architecture

2.2.1 Network infrastructure

i-mode takes benefit of the PDC / PDC-P dual infrastructure, as shown in Figure 3[4].

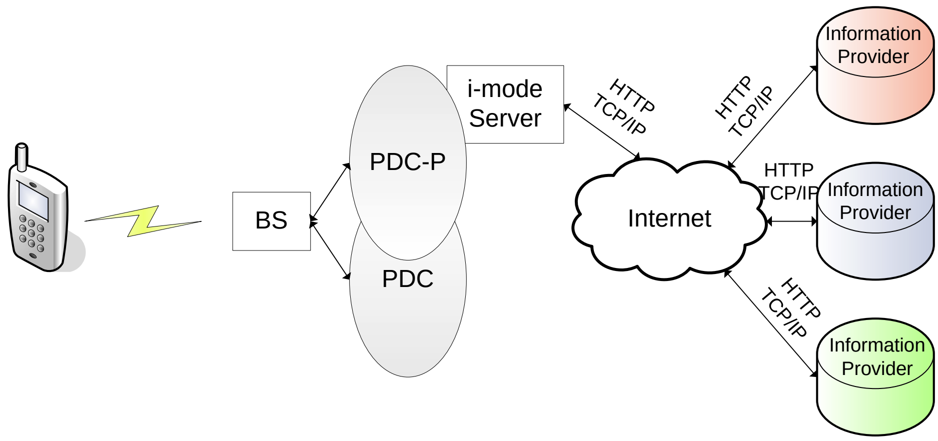

Figure 3: i-mode architecture.

The main network entities are the following:

- Connection endpoints: i-mode enabled cellular phones are responsible for presenting a user interface to allow the user to easily navigate content on the i-mode network. They also run a simple network stack to encapsulate user data into network packets. On the other end, Information Providers are responsible for producing and serving i-mode content (whose details are explained in Section 3.)
- Transport: The PDC-P network transports data packets between the i-mode server and the i-mode phones.
- Proxy: the i-mode gateway acts as a proxy to allow communication between the Packet Network and Internet resources. It can either forward packets out on the public Internet,

[4] Adapted from [Tak01].

or over leased lines directly connected to Information Providers (*e.g.* DoCoMo's portal and mobile content).

2.2.2 i-mode and the Packet Network

By default, i-mode uses the 9600bit/s mode of the PDC-P network. The communication between the i-mode Gateway and the other parts of the PDC-P network is detailed in Figure 4.

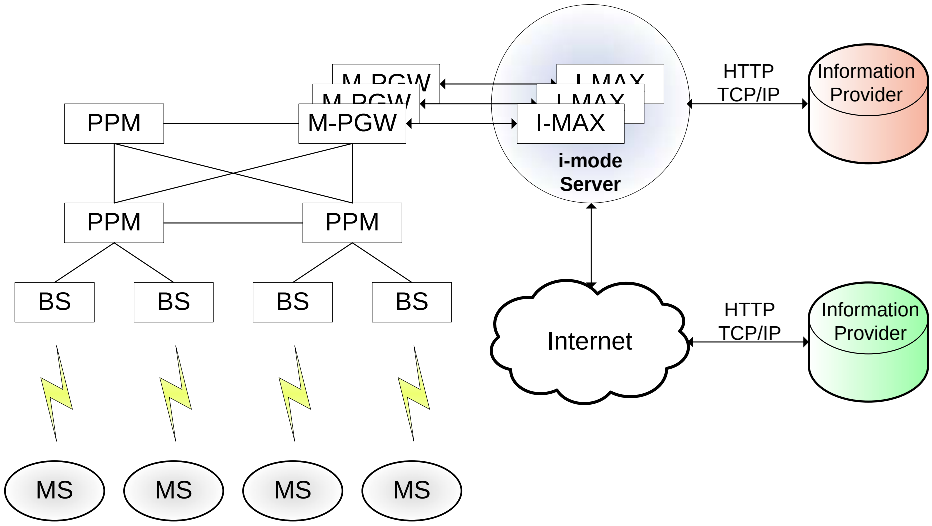

Figure 4: i-mode and PDC-P.

The flow of packets and information is as follow:

- Each MS sends packets to its assigned BS.
- The PMM forwards packets from the MS to the M-PGW.
- The M-PGW is responsible for terminating connections from the MS and the i-mode gateway and interconnecting them together. First, the M-PGW translates the transmission protocol from the optimized proprietary format used by i-mode, DoPa (*i.e.* DoCoMo Packet[5]), to the standard TCP protocol used everywhere else in the PDC-P network. Multiple M-PGWs are installed in the network for load distribution and reliability. The PPM selects the M-PGW on a connection granularity sequentially in a round-robin basis. This is done by having each M-PGW setting up a single TCP session to every corresponding I-MAX, and multiplexing packets through these connections.
- The i-mode Gateway also has multiple interfaces to the PDC-P network, which are called I-MAXs (Interface Mobile Access Exchange). Like the M-PGWs, the I-MAXs are selected sequentially on a round-robin basis. This selection is done by the mobile station, which chooses a different I-MAX for every connection.

2.2.3 i-mode Gateway

The internals of the i-mode server (*a.k.a* Gateway) are shown in Figure 5[6].

The i-mode Gateway has the following main functions:

- Gateway between the MS and the public and private web servers on which i-mode content is available.

[5]More information at `http://dopa-web.nttdocomo.co.jp/` (in Japanese).
[6]Adapted from [DoC99].

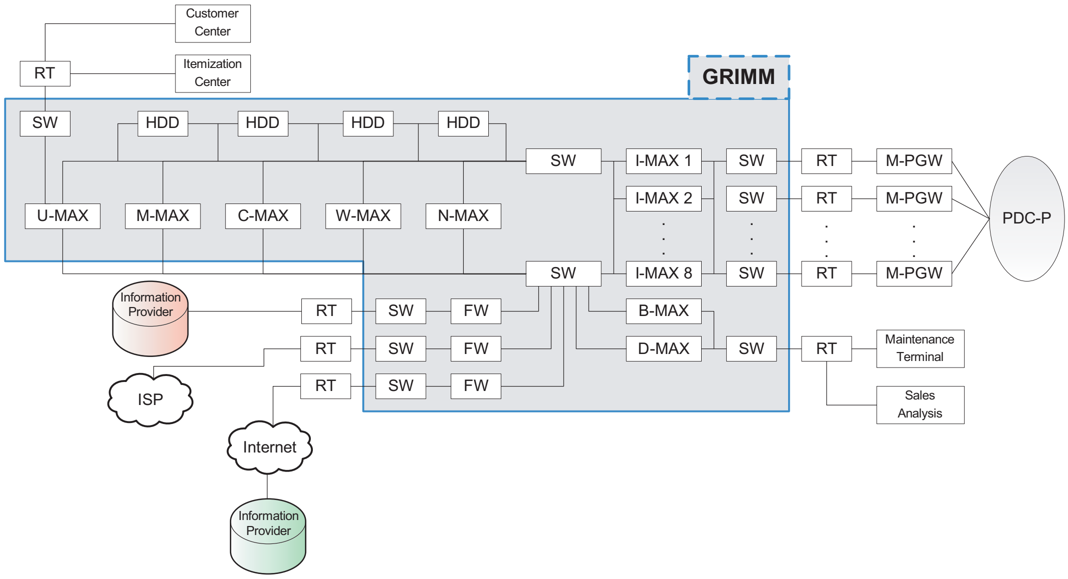

Figure 5: i-mode Gateway.

- Mail storage function on HDD (hard-disk drives) for e-mails ("i-mode mail") through SMTP, as well as pending downloads and transfers to the MS.
- User management function, including AAA, subscription management, and storage of user preferences. For instance, the Gateway tracks and records IP Packet usage, which in turn enables per-traffic accounting and billing.

NTT's part of the i-mode Gateway is called GRIMM – Gateway Service Representative Internet Market Mobile Access Exchange, and the main idea behind it is "responsibility sharing": each component in the architecture has a certain specific responsibility. Components may then be replicated to ensure reliability and load-sharing in response heavy demand. For instance, at the launch of i-mode in 1999, GRIMM was a monolithic system located in NTT's headquarters in Tôkyô. Due to the impressive growth in i-mode usage ever since, several of its subsystems have been cloned and distributed all over the country, thus making the Gateway a distributed and scalable environment.

Switches (SW), routers (RT), and firewalls (FW) connect the Gateway to the PDC-P network as well as other public (Internet, ISPs,...) and private (maintenance, monitoring,...) networks. The main functional components of GRIMM are:

- Business Mobile Exchange (B-MAX): controls the maintenance terminals.
- Content Mobile Access Exchange (C-MAX): performs content processing and forwarding. For *Pull* type content, the Information Provider sends information to the C-MAX, which optionally alters the content per user preferences and forwards the content to the user. For *Push* type content, the users or the IP can decide which users will receive the content updates.
- Database Mobile Access Exchange (D-MAX): collects and analyzes marketing data, based on i-mode site traffic, service use, and other metrics.
- Interface Mobile Access Exchange (I-MAX): as mentioned previously, connects to M-PGW terminals and to other server modules and performs load balancing using a round-robin method.
- Mail Mobile Access Exchange (M-MAX): transmits SMTP mail to and from the MS and stores the mail on a HDD before it is downloaded to the MS.

- Name Mobile Access Exchange (N-MAX): manages mail account usernames selected by subscribers, who can freely change mail addresses on a first-come, first-served basis. It also stores subscriber PIN codes used for mail and site access.
- User Mobile Access Exchange (U-MAX): serves as a master database of i-mode subscriber information, including passwords. It is updated from Customer Center once every 24 hours.
- Web Mobile Access Exchange (W-MAX): acts as the local content server for i-mode. It provides the default i-mode menu displayed on the MS, stores individual subscribers' "My Menu" pages, and delivers region-specific content and interface.

When a user tries to register to an i-mode service, its MS first transmits a request via an M-PGW to an I-MAX. I-MAX relays the request to W-MAX (which stores subscriber-specific "My Menu" pages), N-MAX (to access subscriber's PIN code), and U-MAX (to look up subscriber's information). After verifying that the subscriber's information is valid, I-MAX queries the MS for the PIN code (which the subscriber is prompted to enter). I-MAX, W-MAX, and N-MAX then cooperate to verify the PIN and, if it is valid, allow the registration. The three servers then send a registration notification back to the MS.

2.2.4 Protocol stack

The delivery protocols in use in i-mode are shown in Figure 6[7].

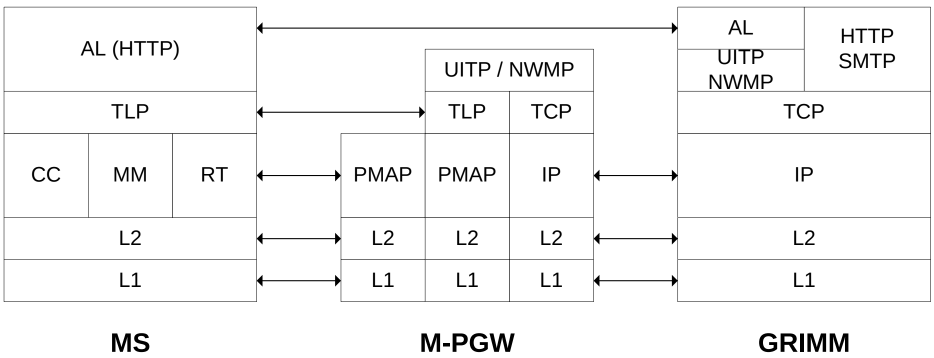

Figure 6: i-mode Protocol Stack.

i-mode does not depend on L1 and L2 protocols designs (however, latency and time-out issues have been caused by the air interface to the i-mode Gateway). On top of that, the network and transport layers are a modified and simplified version of the ones found in DoPa.

Indeed, due to the very nature of the content served through i-mode (mainly text and small images and light multimedia content), NTT's designers chose not to implement the full TCP/IP or PPP suites found in DoPa. Instead, the MS and the M-PGW use a proprietary packet-switching protocol, TLP (Transport Layer Protocol), which is designed to be less bandwidth intensive. GRIMM does implement TCP/IP as it needs to serve as a gateway to Internet and other public, standard networks.

Above the transport layer, i-mode implements a specific session protocol – User Information Transfer Protocol (UITP). UITP is used to manage sessions between the MS and GRIMM, using a Mobile Subscriber Number unique to each MS. Between the M-PGW and GRIMM is also implemented the Network Management Protocol (NWMP), which forwards termination signaling, message-waiting notification (*e.g* an email message is in the user's Inbox), and the packet communication status between the M-PGWes.

As for the application layer, i-mode is built on two main protocols: HTTP and SMTP. To optimize the transfers to the MS, DoCoMo has developed a trimmed-down version of HTTP, AL (Application Layer Protocol), which removes the HTTP headers as well as making additional checks

[7] Adapted from [Tak01].

on the state of the MS (*e.g* checking if there is enough memory before pushing content to the MS). The conversion between AL and HTTP is transparent to the end-user, and is taken care of by the i-mode Gateway.

2.3 i-mode content

2.3.1 cHTML

As underlined in [Nat03a] by Takeshi Natsuno, the inventor of i-mode, the "keystroke" of the success of the service was the choice of the description language used by the system. Contrary to WAP that uses a specifal language – WML (Wireless Markup Language), i-mode uses a subset of HTML, in the forms of cHTML (compact HTML).

It is a markup language that takes features from HTML 2.0, 3.2 and 4.0, with no support for tables, frames, style sheets, fonts, nor backgrounds. It also includes some specific tags for shortcuts to phone numbers[8]. cHTML browsers in i-mode phones only support GIF and animated GIF formats, and web pages are limited to 5KB within DoCoMo's realm.

However, i-mode has extended cHTML in several ways over the years, as the network capacity increased and demands changed. For instance, DoCoMo now uses "emoji" tags to display additional, picture-like, symbols and animations on the web pages[9].

2.3.2 SMTP

i-mode mail is based on SMTP mail, with some accommodations made for network and MS limitations. For example, there is a 500-byte text limit to each message, and attachments are not allowed.

2.3.3 SMS

SMS service is available, with a 25 double-byte (UTF-16) character limit. It is somewhat redundant to e-mail and the absence of traffic exchange agreements with overseas operators has kept the usage of SMS low.

3 i-mode services and content

3.1 Major services

Besides a solid technology, a key feature of i-mode is the large size of the content portfolio available. From the start, and as explained in [Nat03a], the content has been divided into four distinct categories:

- E-commerce: mobile banking, transportation ticket reservations, shopping.
- Information: newsflashes, electronic editions of major newspapers, weather information, maps and localization.
- Databases: Search dictionaries, yellow pages, directories.
- Entertainment: wallpapers, ringtones, radio, games, events.

3.2 The terminals

Another key feature leading to the success of i-mode has been the collaboration with Japanese phone-makers, such as Sony, NEC and Panasonic, to develop the associated terminals. The first

[8] A full reference of the complete tags in cHTML in available in the W3C submission of cHTML: `http://www.w3.org/TR/1998/NOTE-compactHTML-19980209/`.

[9] An extensive list is available on DoCoMo's website: `http://www.nttdocomo.co.jp/english/i/tag/emoji/`.

ones at the launch of the i-mode in 1999, the 501i series[10], were quite limited (black & white screens, text-based navigation), but features have been added to every successive series. For instance, the launch of the 506i series on May 19th 2004 has brought 2M pixel cameras, bar-code scanners, and GPS among others[11] to enhance i-mode capabilities and services.

3.3 i-αppli

A major step for i-mode was reached in January 2001 with the launch of i-αppli[12], a service based on J2ME technology to download and run applications and games directly on the terminals. The use of Java enables both stand-alone (directly downloaded from the Information Provider's site) or agent-based applications (monitoring and updating of information such as weather and stock quotes).

As detailed in [Meg02], i-mode uses Connected Limited Device Configuration (CLDC) profiles in conjunction with the K Virtual Machine (KVM) Java virtual machine. However, NTT DoCoMo has developed its own profile which is incompatible with Sun's Mobile Information Device Profile (MIDP). Indeed, it provides extension APIs to the normal CLDC, by allowing abstracted access to the GUI on the user's terminal as well as low-level graphics controls, as shown on Figure 7[13].

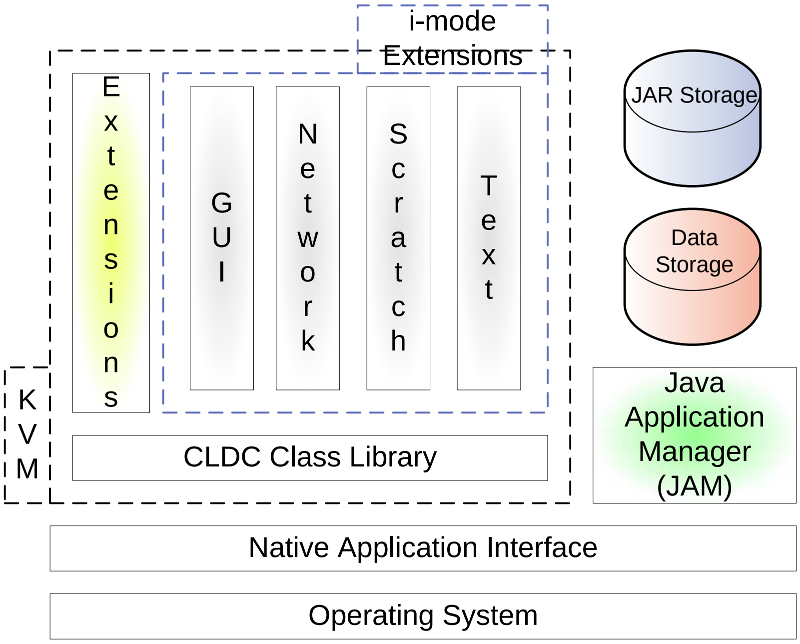

Figure 7: J2ME with i-mode.

In order to develop i-αpplis, NTT as well as third parties provide emulators and SDKs, with extensions specific to the various phone models currently in use in Japan.

4 Market success

It would be restrictive to think that i-mode is just about a technology or a platform for web services: one of its unique aspects was to build a business and revenue model as well as a delivery framework

[10] Each phone series consists of phones from different vendors that share a common set of features. They are then co-branded with DoCoMo when launched on the market. The example of the 501i series can be found at `http://www.we-re.net/info/terminal/docomo/501i.htm`.
[11] `http://www.nttdocomo.com/presscenter/pressreleases/press/file/20040427_attachment.pdf`
[12] `http://www.nttdocomo.com/corebiz/imode/services/iappli.html`
[13] Adapted from [DoC00].

that works in synergy with the internal technology[14].

4.1 Business Model

Contrary to occidental telecommunication operators, NTT DoCoMo has not tried to place itself as the one-stop and obligatory intermediary between the end-user and the service providers nor becoming itself a content provider. Instead, it has devised a model in which all parties benefit from the growth in the number of subscribers and stimulate each other, as shown in Figure 8[15]: an unusual three-way business relationship that needs to be carefully balanced to turn out well.

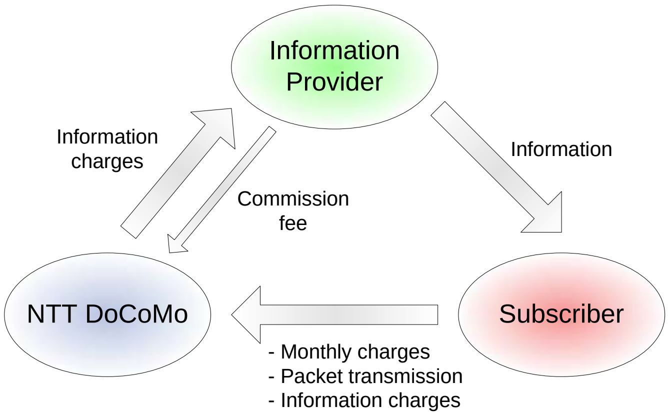

Figure 8: The i-mode "virtuous circle".

In practical terms, each subscriber pays a fixed fee (300¥/month[16]) to connect to the i-mode service, and then pays each service independently, either directly to DoCoMo (mail services, i-shots, i-animations), or to the corresponding Information Provider (*e.g* monthly subscription to Asahi Shimbun: 300¥; ringtones downloads from Xing: 300¥). In addition to that, there is a fixed cost per packet(128 bytes) transmitted, which depends on the actual subscription[17], and is generally around 0.3¥.

However, a sensible price strategy is not enough: as underlined in [Nat03b], several important decisions have played a critical role in making i-mode a sustained growing service, as the subscriber figures clearly show: 1 million subscribers after 6 months of operation in August 1999, 5 million in February 2000, 24 million in February 2001, and 41.3 million as of April 2004[18].

- Making the life of Information Provider as easy as possible: the motivation behind the choice of cHTML has already been mentioned, and was followed by the adoption of cMIDI (compact MIDI) for ringtones. Keeping the same IT infrastructure has allowed a rapid kickstart of the i-mode service[19]. Ironically, WAP adopted the completely opposite approach, bringing the results we all know.

- Designing a seamless user experience: to make i-mode what it is today, a part of ordinary life, a progressive introduction of the service has been done. First came the simple download of wallpapers and animations, then ringtones, then execution of external programs. Not only has it created a smooth transition from cheap PHS service to the more full-fledged i-mode, but it also gave time for the subscribers to "absorb" the technological innovation over time.

[14] I do not have the pretention of explaining the whole *ecosystem* of i-mode in a few paragraphs. [Nat03a] and [Nat03b] are fascinating references for understanding it.

[15] Adapted from [Vin01].

[16] According to `http://www.nttdocomo.co.jp/p_s/f/mova_imode.html`.

[17] `http://dopa-web.nttdocomo.co.jp/15/index.html` for price matrix.

[18] `http://www.nttdocomo.com/companyinfo/subscriber.html`

[19] NTT proudly announced 67 providers on the day of the launch in February 22nd 1999, as written in [Nat03a].

- Working hand-in-hand with phone manufacturers, the network infrastructure and Information Providers to provide an end-to-end experience. It is this careful mix of control and cooperation, the balance between proprietary and open solutions that brings forth the synergies needed to i-mode.

4.2 Exporting i-mode

Following the impressive growth of i-mode in the Japanese domestic market, the service was launched in Germany (through E-Plus) in March 2002. Since then, DoCoMo has partnered with local providers to offer i-mode services in France (Bouygues Telecom), Spain (Telefonica), Italy (Wind Telecomunicazioni), Belgium (BASE), The Netherlands (KPN), and Taiwan (KG Telecommunications).

Such alliances were first motivated by strengthening the position of DoCoMo overseas against its competitors (*e.g.* J-Phone, which is part of Vodafone). As Natsuno explains in [Nat03b], it is not only to gain shares in the foreign telecommunication providers, but also "to acquire new technologies, ideas, and business models" that "will contribute to the further development of i-mode".

However, as i-mode arrived during the transition between WAP and GPRS (at least in Europe), it turned out to have a niche market and to be used as a tool for differentiation: the lack of shared interest among telecommunication providers has limited its widespread adoption, and in those countries, i-mode is primarily seen as the alternative.

5 Conclusion

i-mode combines an innovative technology with a distinctive business model to make the most of 2G cellular systems. It shows that despite network limitations (9.6kbit/s, then extended to 28.8kbit/s in May 2002), profitable services can be developed and successfully marketed.

While benefiting from the growth of i-mode, DoCoMo also invested in developing the next step: a full 3G network taking i-mode services to a new level. As underlined in [Tac03], it was the first provider to launch an IMT-2000 network in October 2001: FOMA[20] (Freedom Of Mobile multimedia Access). Not only does it extend i-mode services by providing video services as well as higher-quality multimedia streaming, but it also paves the way towards an "all-IP" mobile environment.

Note

References

[Anw02] Syed Tariq Anwar. NTT DoCoMo and m-commerce: A case study in market expansion and global strategy. *Thunderbird International Business Review*, 44(1):139 – 164, January/February 2002.

[DoC99] NTT DoCoMo. *NTT DoCoMo Technical Journal*, 1(1), October 1999.

[DoC00] NTT DoCoMo, editor. *i-mode Java Content Developer's Guide*. 2000.

[DoC03] NTT DoCoMo, editor. *i-mode User's Manual*. 2003.

[20] `http://foma.nttdocomo.co.jp/english/`

[Eno01] Keichi Enoki. i-mode: The Mobile Internet Service of the 21st Century. In *International Solid-State Circuits Conference*, pages 12 – 15, February 2001.

[HNU95] Shoichi Hirata, Akihisa Nakajima, and Hisakazu Uesaka. PDC mobile packet data communication network. In *Fourth IEEE International Conference on Universal Personal Communications*, pages 644 – 648, November 1995.

[IKYI96] Takeo Ichikawa, Hidetoshi Kayama, Hiroyuki Yamamoto, and Yasuhiko Inoue. PHS terminating call control. In *IEEE International Conference on Converging Technologies for Tomorrow's Applications*, pages 818 – 822. IEEE, June 1996.

[IKYI97] Takeo Ichikawa, Hidetoshi Kayama, Hiroyuki Yamamoto, and Yasuhiko Inoue. PHS with packet data communications (PHS-PD) protocol architecture. In *Vehicular Technology Conference*, pages 416 – 420. IEEE, May 1997.

[Ish04] Kenichi Ishii. Internet use via mobile phone in Japan. *Telecommunications Policy*, 28(1):43 – 58, February 2004.

[KBL+03] Bo Karlson, Aurelian Bria, Peter Lönnqvist, Cristian Norlin, and Jonas Lind. *Wireless Foresight – Scenarios of the Mobile World in 2015*. John Wiley & Sons Ltd, 2003.

[KF01] Anri Kivimäki and Vladislav Fomin. What makes a killer application for the cellular telephony services? In *Standardization and Innovation in Information Technology*, pages 25 – 37. IEEE, October 2001.

[Kod01] Mitsuru Kodama. Strategic community-based theory of firms: case study of dialectical management at NTT DoCoMo. *Systems Research and Behavioral Science*, January 2001.

[Kod02] Mitsuru Kodama. Transforming an old economy company through strategic communities. *Long Range Planning*, 35(4):349 – 365, August 2002.

[Kri01] Jan Krikke. Graphics applications over the wireless web: Japan sets the pace. *Computer Graphics and Applications*, 21(3):9 – 15, May/June 2001.

[Mag04] Gerald Q. Maguire. *2G1330 Mobile and Wireless Network Architectures*. 2004.

[Meg02] Veronika Megler. i-mode: From bandwidth problem into Internet phenomenon. *IBM developerWorks*, June 2002.

[MMOH97] A. Murase, A. Maebara, I. Okajima, and S. Hirata. Mobile radio packet data communications in a TDMA digital cellular system. In *Vehicular Technology Conference*, pages 1034 – 1038. IEEE, May 1997.

[Nat03a] Takeshi Natsuno. *i-mode Strategy*. John Wiley & Sons Ltd, 2003.

[Nat03b] Takeshi Natsuno. *The i-mode Wireless Ecosystem*. John Wiley & Sons Ltd, 2003.

[NY01] Nobuo Nakajima and Yasushi Yamao. Development for 4th generation mobile communications. *Wireless Communications and Mobile Computing*, 1(1):3 – 12, January/March 2001.

[OSSF03] Masafumi Onuki, Kazuo Sugiyama, Koji Sasada, and Hiroshi Fujiya. Mobile packet data communication network and its implementation. *Electronics and Communications in Japan (Part I: Communications)*, 86(4):72 – 85, April 2003.

[RM03] Kris Read and Frank Maurer. Developing mobile wireless applications. *IEEE Internet Computing*, 7(1):81 – 86, January/February 2003.

[SMY+02] Toshihiro Suzuki, Akira Miura, Keiko Yoshihara, Ryutaro Matsumura, Masayuki Inoue, and Hiromichi Kawano. Evaluation of the performance of the mobile packet communications network. *Workshop on Merging Optical and IP Technologies*, pages 300 – 308, 2002.

[Tac03] Keiji Tachikawa. A perspective on the evolution of mobile communications. *IEEE Communications Magazine*, 41(10):66 – 73, October 2003.

[Tak01] Atsushi Takeshita. Toward mobile multimedia in next generation networks. In *Applications and the Internet Workshops*, pages 194 – 198, January 2001.

[TNY93] Hideo Takamura, Akihisa Nakajima, and Koji Yamamoto. Network and signaling structure based on personal digital cellular telecommunication system concept. In *Vehicular Technology Conference*, pages 922 – 926. IEEE, May 1993.

[Vin01] Geoff Vincent. Learning from i-mode. *IEE Review*, 47(6):13 – 18, November 2001.