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Mobile healthcare informatics

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Abstract
Advances in wireless technology give pace to the rapid development of mobile applications. The coming mobile revolution will bring dramatic and fundamental changes to our daily life. It will influence the way we live, the way we do things, and the way we take care of our health. For the healthcare industry, mobile applications provide a new frontier in offering better care and services to patients, and a more flexible and mobile way of communicating with suppliers and patients. Mobile applications will provide important real time data for patients, physicians, insurers, and suppliers. In addition, it will revolutionalize the way information is managed in the healthcare industry and redefine the doctor–patient communication. This paper discusses different aspects of mobile healthcare. Specifically, it presents mobile applications in healthcare, and discusses possible challenges facing the development of mobile applications. Obstacles in developing mobile healthcare applications include mobile device limitations, wireless networking problems, infrastructure constraints, security concerns, and user distrust. Research issues in resolving or alleviating these problems are also discussed in the paper.

Keywords: *Health information systems, healthcare, telemedicine, mobile and wireless applications, mobile services*

1. Introduction

In the past few years, wireless devices, such as handheld PCs, PDAs, messaging devices, electronic organizers and smart phones, have become increasingly popular and common. Statistics show that a population of over 850 million—or about 14 percent of the world population—owns one or more mobile phones. This has generated sales of over 400 million mobile phones worldwide by the end of 2001, and over 6 million personal digital assistants (PDAs) by 2000 [1]. Mobile-devices ownership is largely boosted by the evolution of mobile telecommunication networks and mobile Internet. The mobile Internet and wireless technologies have expanded current Internet sales and services channels into more immediate and personalized mobile environments, offering more responsive and competitive solutions for the enterprises. The coming mobile revolution will bring dramatic and fundamental changes to our daily life. It will influence the way we live, the way we work, and the way we play. Along with the mobile revolution, mobile healthcare is revolutionalizing the healthcare industry.

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Mobile healthcare, also known as m-health, is the development, dissemination and application of mobile information and wireless telecommunication technologies in the area of healthcare. Mobile technologies can be applied to healthcare in various ways such as voice communication, messaging, notification, asset tracking, and remote access. Adding mobility to healthcare delivery can improve healthcare provider responsiveness and healthcare consumer satisfaction, streamline the healthcare processes and enhance business agility. In addition to that, healthcare mobility can increase productivity, reduce administrative cost, and enhance overall service quality.

This paper primarily focuses on the wireless applications in healthcare. It examines enabling mobile technologies and infrastructure, highlights the key drivers for mobile healthcare and potential mobile applications in healthcare, points out the organizational challenges in adopting and implementing m-healthcare, and discusses technical obstacles, possible solutions and future research in applying mobile technologies in healthcare.

2. Mobile communication technologies

The growth of mobile services will depend on the development and deployment of enabling technologies. These technologies include, but are not limited to, network technologies, service technologies, mobile middleware, mobile commerce terminals, mobile location technologies, mobile personalization technologies, and content delivery and format. Presented below are some of the major technologies that are making mobile services a reality:

- *GSM*: Operating in the 900 MHz and 1800 MHz (1900 MHz in the US) frequency band, Global System for Mobile Communication (GSM) is the prevailing mobile standard in Europe and most of the Asia-Pacific region. It also serves as the basis for other network technologies such as HSCSD (high-speed circuit switched data) and GPRS (general packet radio service). The wide adoption of the GSM standard makes it economically feasible to develop innovative mobile applications and services.
- *SMS*: Short Message Service (SMS) enables text messages to be sent to and received from mobile phones. Currently, up to 160 alphanumeric characters can be exchanged in each SMS message. Widely used in Europe, SMS works through voice mail notification and is a form of simple person-to-person messaging. It also provides mobile information services, such as news, stock quotes, sports, and weather. SMS chat is the latest feature and is growing in popularity.
- *WAP*: Wireless Application Protocol (WAP) is an open and global standard for mobile solutions, designed specifically to deliver web information to mobile terminals. As an end-to-end application protocol, it attempts to provide solutions to the challenges in developing mobile applications, such as connecting mobile terminals to the Internet and making mobile terminals become communication devices capable of communicating with other devices over a wireless network. It also supports the design of interactive and real-time mobile services.
- *UMTS*: Universal Mobile Telecommunications System (UMTS), the so-called 'third-generation (3G)' technology, aims to offer higher-bandwidth, packet-based transmission of text, voice, video, and multimedia needed to support data-intensive applications. Once UMTS is fully implemented, computer and phone users can be connected to the Internet continuously and have access to a consistent set of services worldwide. Integrating the functions of a whole range of different equipment, a 3G mobile phone can be used as a phone, a computer, a television, a paper, a video conferencing centre, a newspaper, a diary, and a credit card.

- *Fourth-Generation Technologies*: Although 3G technologies are just emerging, research has commenced on fourth-generation (4G) technologies. These research initiatives encompass a variety of radio interfaces and even an entirely new wireless access infrastructure. Better modulation methods and smart antenna technology are two of the main research areas that will enable fourth-generation wireless systems to outperform third-generation wireless networks [2].
- *Bluetooth*: Bluetooth, named after a tenth-century Danish king who conquered Scandinavia, is a low-power radio technology for communication and data exchange. Using a single chip with built-in radio-transmission circuitry, Bluetooth is an inexpensive short-range wireless standard supporting local area networks (LANs). It was developed to replace the cables and infrared links within a 10 m diameter. Bluetooth can be used to link electronic devices, such as PCs, printers, mobile devices, and PDAs, to wireless data networks.
- *GPS*: Global Positioning System (GPS) is a system of satellites orbiting the Earth. Because the satellites are continuously broadcasting their own position and direction, GPS receivers can calculate the exact geographic location with great accuracy. Originally developed in the US for military use, GPS is now also used for civilian purposes. For example, GPS is used in car navigation systems.
- *XML*: eXtensible Markup Language (XML) is a meta-language, designed to communicate the meaning of data through a self-describing mechanism. It tags data and puts content into context, thereby enabling content providers to encode semantics into their documents. For XML-compliant information systems, data can be exchanged directly even between organizations with different operation systems and data models, as long as the organizations agree on the meaning of the data that are exchanged. XML is heavily used in mobile applications development.
- *WML*: Wireless Markup Language (WML), derived from XML, has been developed especially for WAP. It allows information to be represented as cards suitable for display on mobile devices. So, WML is basically used in WAP, like HTML is to the Internet.
- *Wi-Fi*: Wi-Fi stands for *wireless fidelity*. Wi-Fi networks use 802.11 specifications (developed by IEEE for wireless LAN technology to specify an over-the-air interface between a wireless client and a base station or between two wireless clients) to provide secure, reliable, fast wireless connectivity. Wi-Fi networks operate in the unlicensed 2.4 and 5 GHz radio bands, and can provide real-world performance similar to the wired Ethernet networks used in many offices. Products tested and approved as 'Wi-Fi Certified' are interoperable with each other, even if they are from different manufacturers.

3. Key drivers and potential M-health applications

For the healthcare industry, mobile applications provide a new frontier to provide more responsive and convenient care and services to the patients, and more flexible and mobile ways of communicating with suppliers and partners. Mobile healthcare will enable healthcare stakeholders to request services, provide cares, access databases, track inventory, communicate, exchange data, and perform many other tasks. Mobile healthcare has the ability to address the needs of customers and businesses that cannot be met in traditional healthcare and can provide more convenient services with enhanced responsiveness and flexibility. In this section, we first discuss some of the key drivers and potential applications of mobile healthcare, and then illustrate our discussions with a hypothetical case of the use of mobile technology in emergency healthcare.

3.1. Mobility and mobile data access and exchange

Mobile e-mail and the Internet enable instant data and information exchange, and facilitate information sharing and interactivity to help cope with complex healthcare environments. Mobility, the primary advantage of mobile applications, integrated into organizations' operation has the potential to make information flow more efficiently and to better coordinate operations within the healthcare supply chain [3], thus creating many new opportunities for the healthcare world to embrace. Specifically, WAP-enabled wireless devices make data access and information sharing possible anytime and anywhere. Extensible markup language (XML) and Wireless markup language (WML) enable data to be exchanged directly, even between organizations with different operation systems and data models, as long as the organizations agree on the content of the data that are exchanged.

The continuous connectivity which mobile technology and wireless infrastructure are enabling has the promise to fulfil the healthcare industry's need for real-time information and anytime, any place communication. With an Internet-enabled mobile phone, doctors can access hospitals' databases, retrieve information, and view laboratory results and imaging reports while they are on the move. Similarly, healthcare consumers can use the WAP-enabled mobile phone to search hospitals' websites for relevant information and schedule or re-schedule appointments.

3.2. Ubiquity and time-sensitive applications

The always-reachable feature of mobile devices makes it possible for healthcare consumers to contact medical personnel through mobile devices wherever and whenever such a need arises. Meanwhile, physicians and nurses are also able to stay in touch while they are on the move, from clinic to hospital, from room to room, and from bedside to bedside. The short message service (SMS) could be used to send people short messages notifying them of the latest update of patient information. As doctors and nurses communicate more often, PDAs, tablet PCs, and laptop computers, which can be connected by wireless networks, are becoming as much a part of a doctor's bag as a stethoscope.

With a laptop, a GSM modem and a connected mobile phone, physicians doing out-patient visits can dial into hospitals' network mail server and stay in touch with their organizations while on the move. They are able to access immediate and complete information about their patients, such as family and medical history, personal information, medication, illness, disease, and so on. They can also prescribe medication, consult with colleagues, change treatment, obtain insurance information, and more while on the go. In addition, field technicians in healthcare supply organizations are able to use mobile devices to communicate logistics, machine status, customer information, and order billing information.

In addition, mobile applications have the ability to provide customers automated and unassisted operations directly from mobile terminals connected to the Internet. For example, patients using a wireless instrument will be able to receive notification to take medication. In the not-too-distant-future, a patient can wear a wristband that is connected by wireless mobile communications to the Internet. This will continuously send the patient's electrocardiogram to the physician's computer system though the Internet. The physician will be alerted automatically when an abnormality is identified. In this way, a life-threatening medical condition can be detected early, and the physician will be able to make an informed decision with the real-time clinical information. These automated services will provide healthcare consumers time-sensitive care with improved flexibility over traditional methods.

3.3. Positioning and location-based service

A number of technologies for determining locations of mobile devices in use are available. Global Positioning Systems (GPS) is one of the most widely used location-identification technologies. The positioning technologies can be applied to pinpoint the location of people or assets for tracking purposes and emergency services, and for location-relevant applications such as driving direction and traffic reports [4]. For example, positioning technologies can provide maps and routes to the nearest clinic or hospital when a patient needs medical attention or treatment. In addition, it can save the life of the patient if the doctor knows where the patient is at times of emergencies. In short, the knowledge of a user's physical location at a particular moment enables healthcare providers to deliver extra convenience and value-added services.

In addition, mobile applications can push information, such as healthcare plans and healthcare services, to mobile users, putting them in a better-informed position. Being able to track the user's position, healthcare insurers, suppliers and providers are able to tailor services and promotional offers accordingly.

3.4. Personalization and personalized applications

Mobile devices, especially mobile phones and PDAs, are becoming the most personal computing devices we use. These devices are capable of identifying our personal preferences and daily routines, such as our whereabouts and activities. On the other hand, although enormous amount of information, services, and applications are currently available on the Internet, not all information is relevant to all users. Mobile applications can be personalized to filter information or provide services in ways appropriate to a tailored user.

Personalization is a powerful feature inherited in mobile applications and presents healthcare providers new opportunities in delivering more relevant services. In the future, personalized applications will offer a single sign-in service. For example, doctors and nurses will no longer need to log in multiple times and memorize multiple passwords when they access the databases of different organizations from their hand-held devices from remote sites. They will only need to log on once per session to gain access to all the databases they have access to. Personalized applications will benefit healthcare consumers as well. The patients will be able to check into the hospitals with their Internet-enabled mobile phones after providing relevant personal information. Personalized applications have the ability to store the patients' personal information, and selectively re-use it when billing the patients' account and when preparing checkouts for them. In this way, redundancy of data entry and time spent on documentation will be reduced, making the process of hospitalization more cost-efficient.

3.5. An illustration—mobile applications in emergency service

An emergency call is made to an emergency room via a mobile phone on the site of a car accident. With the mobile technology to pinpoint the location from which the emergency call is placed, the medical personnel in the emergency room contacts the ambulance service that is closest to the site of accident. Along their way to help, the medical professionals from the ambulance service use the location identification technologies for location-sensitive traffic information to arrive at the destination as soon as possible. At the same time, with laptops or mobile phones, they can transmit the patient's information, such as blood type, medication and allergies, to the emergency room, constantly update the patient's condition to the emergency room, and report the estimated arrival time.

Meanwhile, the nurse in the emergency room prepares for the arrival of the patient by cleaning the ward and mobilizing equipment. The physician receives a short message moments before the patient's arrival, and makes himself/herself available for the coming patient. While the physician works on the patient, the nurse can input admission information using a wireless hand-held device. With their mobile devices constantly connected to mobile networks, the physician and nurse in the emergency room can be notified of the latest update of patient information regardless of their locations in the emergency room. For example, the nurse can be notified of the ordering of lab tests by physician and the status of the lab test by the lab via short messaging. Such real-time communication enhances medical staff's contextual awareness and reduces unnecessary time in waiting and walking around for relevant information.

After the patient is discharged from the emergency department, the patient can receive notification to take medication via a wireless device and can send a confirmation to tell the service that s/he has done so. The patient will also be able to refill prescriptions and receive important medical news regarding his/her diseases or conditions.

4. Organizational challenges

The prospect of mobile healthcare may appear obvious to many, but the path to success is not straightforward. The development of mobile healthcare applications is complicated by technical limitations of mobile devices and wireless communication, and business and regulatory concerns. In this section, we elaborate on the organizational challenges and technical obstacles when adopting mobile applications in healthcare.

4.1. Fundamental changes in business strategies and processes

Healthcare providers need to redesign their organizational processes and rethink their roles to fully integrate mobile applications. In other words, in order to stay competitive, strategic transformations have to be made, and genuine benefits from mobile applications should be recognized. Healthcare providers will have to make fundamental changes in organizational behaviour, develop new business models, and eliminate the inefficiencies of old organizational structures. The process of rethinking and redesigning is a demanding task. Implementing mobile healthcare is more than developing a website on the mobile Internet. It involves rethinking and re-engineering the way healthcare was being delivered. For example, unlike traditional healthcare delivery, where patients play a passive role, patients are expected to participate actively and share responsibility for all aspects of their care in mobile healthcare. The trend of self-educated patients makes healthcare providers rethink their roles and reposition themselves in healthcare delivery.

4.2. Huge investment in mobile infrastructure and expertise

A major problem faced by mobile applications in healthcare is the huge investment required for their implementation and operation. Engineering massive organizational and system changes to strategically reposition an organization is complicated as well as expensive. For example, a hospital will have to build a mobile infrastructure and invest money in mobile devices. Nevertheless, implementing the mobile technology itself does not guarantee that the implementing organization will reap any benefits from mobile applications. Expertise in fields other than technology is also a prerequisite for successful mobile applications. How can organizations obtain a payoff from their investment in wireless technology? Understanding the

costs and benefits of mobile healthcare is difficult, particularly when the technology is changing and evolving at a rapid pace.

4.3. Lack of consumer trust in mobile applications

In each transaction, each party involved needs to be able to authenticate its counterparts, to make sure that received messages are not tampered with, to keep the communication content confidential, and to believe that the received messages come from the correct senders. Owing to the inherent vulnerability of the mobile environment, users in mobile applications are more concerned about security issues involving mobile transactions. According to Marcus [5], US consumers are not ready to buy mobile services. Similarly, healthcare consumers need to be assured that their medical and financial information are secure, and that wireless transactions are safe. The mass adoption of mobile applications and the widespread use of mobile healthcare will not be realized until users begin to trust mobile applications [6].

4.4. Absence of information quality control

The complete absence of information quality control poses another significant challenge for the mass adoption of mobile healthcare. Like the wired Internet, virtually anything can be posted on the mobile Internet. A large quantity of information about medicine and health are available online, from medical professional societies and government agencies to pharmaceutical companies and patient discussion groups. There is no way at this moment for healthcare users to evaluate the completeness, bias, and timeliness of online information, and to ascertain credentials or qualifications of the contributors to discussion groups.

5. Technical obstacles

5.1. Limitations in mobile terminals and mobile networks

While mobile terminals demonstrate a greater extent of mobility and flexibility, they are inferior, in several aspects, to personal computers. The screen is small, and the display resolution is low. The small and multifunction keypad complicates user input. Because they need to be physically small and light, these input and output mechanisms impede the development of user-friendly interfaces and graphical applications for mobile devices. Mobile handsets are also limited in computational power, memory and disk capacity, battery life, and surfability. These drawbacks in mobile devices do not support complex applications and transactions, and consequently limit usage of mobile services in complicated healthcare environments. In addition, mobile networks suffer many limitations as well. Compared with fixed networks, mobile networks have a lower bandwidth, longer delays, and poorer connection stability. All these lead to lower performance.

5.2. Need of interoperability in mobile network standards

Multiple, complex and competing protocols serve as mobile networks standards today. As previously mentioned, GSM is a single standard used by the network operators in Europe and the Pacific Asian region. But TDMA (time-division multiple access) and CDMA (code division multiple access) are widely used in the USA. These different standards have resulted in the global incompatibility of mobile handsets. The network incompatibility poses problems for healthcare providers when communicating with their patients and partners.

5.3. Multiple but incompatible Web languages

In addition to competing networks, the currently available web languages are also incompatible. Newer mobile phones will incorporate WAP and its WML. On the other hand, NTT DoCoMo's iMode uses condensed HTML (hyper-text markup language). The fact that incompatible standards are utilized in mobile devices today makes the process of creating successful m-commerce applications even more difficult. The need for standardization of web languages appears extremely urgent. The mobile communication within organizations and the interactions between healthcare providers, their patients, and their partners will not see significant improvements until the issue of competing web languages is addressed.

5.4. Privacy and security issues

Most people recognize the need to keep medical records and client information confidential, and should not be left lying around for view by unauthorized persons. Unfortunately, legal protection of data confidentiality has been poor until recently. In addition, compared with its wired counterpart, wireless communications are more vulnerable. Although most wireless data networks today provide reasonable levels of encryption and security, the technology does not ensure transmission security in the network infrastructure. Data could be lost due to mobile terminal malfunctions. In addition, these terminals could be stolen, and ongoing transactions can be altered. In short, the mobility enjoyed by mobile applications in healthcare also raises many more challenging security and privacy issues. Serious consideration must be given to the issue of security and confidentiality in developing mobile applications for healthcare.

6. Research issues in mobile healthcare

Much research needs to be done to overcome the hurdles and solve the problems of mobile applications in healthcare. In this section, we delineate the research that should be carried out to address the business challenges and technical obstacles facing mobile healthcare.

6.1. Improve mobile devices' usability and mobile-network infrastructure

Currently, the usability of mobile devices is poor due to the various limitations of mobile terminals. Screens for mobile phones will be made larger, making them easier to read and be more visually appealing. Equally important, the screen resolution for mobile devices must be improved dramatically to facilitate physicians and surgeons when viewing illustrative reports. Meanwhile, offline methods that require no direct connection of mobile devices to the network can help to minimize the technical limitations. Future mobile devices will also support Bluetooth technology, allowing them to access nearby appliances, such as vending machines and televisions, by using low cost short-range moderate bandwidth connections to better healthcare supply chain management. With such capabilities, mobile devices will support a combination of different communication connections to provide a variety of mobile applications in healthcare.

Bandwidth and coverage are major issues for network infrastructure [7]. The former allows more data to be exchanged between servers and mobile devices, thus supporting multimedia content delivery. The latter minimizes the complications of connection losses when a mobile device moves beyond a network boundary or crosses from one network to another. These two

issues directly affect the quality of mobile data transfer, and are therefore critical to the further development and future deployment of mobile healthcare.

6.2. Make interface user-friendly

Unlike the wired computing environment where large screens are available, mobile applications have to operate on small and often wearable mobile devices that can only include small screens. A user-friendly interface on mobile devices is of great practical significance to mobile healthcare, because the mobile healthcare is not aimed at the tech-savvy residents. Many mobile healthcare clients may be senior people, who may be technophobic. Therefore, the interface should be simple in design, and easy to interact with and operate.

Researchers are now developing voice-based and pen-based interaction to replace the present keyboard and mouse interaction. Pen-based interaction on touch screens may replace the mouse; voice-based interaction may be used for activation and control of functions such as voice dialling. Some studies on user interface for mobile devices have been reported in the workshop series on Human – Computer Interaction with Mobile Devices [8].

6.3. Explore new technologies for better wireless connection and access

The limitations inherent in mobile networks, such as low bandwidth, long delays, and poor connection stability, make mobile applications less desirable and appealing. They also result in expensive mobile connection fees and consequently impede the adoption of mobile healthcare. Methods must be found to overcome the mobile-network barriers and to make mobile applications affordable to mobile healthcare consumers.

One way to achieve this goal is to use agent technologies. Agent technologies have the ability to alleviate the problem of high costs of connection time and data exchange for mobile devices. Mobile healthcare consumers can contact mobile healthcare agents to look for medical treatments and services, to locate hospitals, to enquire about cost, and to make payment. All of these activities could be performed without having the mobile devices constantly connected to the network. In an agent-based mobile application framework, agents can be envisioned as merchants, consumers, and other brokering services, interacting with one another to enable electronic transactions.

Another solution is to improve mobile access to databases. To allow users to run applications on their mobile devices without having to maintain constant connection with the servers and pay expensive connection fees, at least part of the database systems must be able to reside on the mobile devices. It will be necessary for these mobile database systems to require little memory and still be able to transfer their data to the centralized database systems or to synchronize their databases with those at the centralized database systems. In some cases, a mobile database system may only manage a portion of a large central database pulling in additional data on demand and pushing back data that are not required. In a mobile environment where users are constantly on the move, and few computing resources are available, query processing and data-recovery capabilities for these mobile database systems will have to be further improved.

While much attention has been given to providing visual access to the mobile Internet at present, voice access can also be employed to enable web content to be displayed on mobile devices. VoiceXML [9] is a new markup language for creating voice-user interfaces to web applications or content using normal telephones. Since most mobile devices can be equipped with voice capabilities, it is important to study how a combined voice, screen and keyboard

(or button) access to the web could be realized by integrating the features in VoiceXML with wireless markup language.

6.4. Enhance compatibility among disparate standards and technologies

Economies of scale, complex healthcare supply chain and healthcare consumer demand for global roaming and affordable services all require interoperability of the many standards and technologies that are enabling mobile healthcare. Web services could enable software components to talk easily to one another across disparate operating systems, web languages, and network standards. They could offer mobile healthcare a powerful and standardized mechanism to enable the participants in the mobile healthcare supply chain to exchange data and information, and share business functionality with ease. Critical interoperability efforts should be launched to pave the way for a higher level of mobile healthcare applications.

6.5. Strengthen security and privacy measures

Research on how to improve security and privacy in mobile applications must be carried out, owing to the need to protect the confidentiality of medical records. To meet security requirements such as authentication, integrity, confidentiality, message authentication, and non-repudiation in mobile commerce, additional security software and features (e.g. certificates, private, and public keys) will have to be installed on mobile devices. However, owing to the limited computing capability of mobile devices, at some point, it might be necessary to establish additional servers to store information, perform security checking, and conduct electronic payments on behalf of mobile devices [10,11].

6.6. Control information quality

Relevant regulatory measures should be taken to safeguard online information on medicine and health in order for it to be complete, timely and devoid of biases. Otherwise, mobile healthcare consumers might obtain misleading information from the mobile Internet, which may have a negative impact on health and medical treatments. Guidelines should be developed for consumers' understanding of online healthcare information and distinguishing quality sources from others.

6.7. Development of new business models for mobile healthcare

Mobile application presents many new opportunities for healthcare providers and suppliers to reduce costs and improve healthcare consumer satisfaction [12]. Because of the unique characteristics of the healthcare industry, new mobile healthcare business models should be developed to design and implement mobile B2B and B2C mobile healthcare applications.

7. Conclusion

The proliferation of mobile devices has been catalysing the use of wireless technologies among doctors and patients. Healthcare practices are set in a revolutionary stage. In the near future, the day-to-day impact of mobile technologies will grow as mobility becomes a part of life and work. Although there remain a number of technical, regulatory, and social challenges to overcome, mobile applications will make a significant and positive contribution to the way we take care of our health.

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