Abstract

This paper presents an analysis of the future of Embedded Linux in the PostPC industry. This analysis is carried out by first examining the current forces at work in the PostPC market and how they effect Linux. Next, we look at the future trends in the PostPC market for the many types of devices we see in the market now and will see in the future and how well these trends can be addressed by Embedded Linux and other RTOSes in the marketplace. The third step in this analysis is to examine the qualities of Linux itself and what gives it an advantage in the marketplace as well as the challenges that accompany using Linux as an embedded platform.

We address the challenges that Embedded Linux faces by proposing the need for the standardization of Embedded Linux. This means building a core standard for a kernel that is optimized for embedded systems, standard middleware profiles for powering different applications, and a standard for addressing intellectual property and software components.

1. Introduction

Since the emergence of Linux as a popular choice for server computing, it has seen a growing amount of interest in many computing domains. Linux has seen little success as a desktop operating system but has been adopted successfully for developer workstations, graphics workstations, and server clustering schemes. The success of Linux is largely fostered by its low cost and similarity to existing Unix systems. Linux has found most of its growth by replacing existing Unix installations and some from being selected as the operating system of choice for new projects that likely would have instead been powered by a variety of proprietary Unix.

The Embedded Linux market is very different from the relatively mature markets that Linux has seen success in thus far. The PostPC industry represents an environment that will foster dramatic growth and new development.

The adoption of Embedded Linux in this market will not be driven by simple replacement of expensive proprietary operating systems. The penetration of Linux into the PostPC market will rely on the ability of Linux to leverage its other advantages, such as open source licensing and a strong developer community.

In this paper we present a thorough analysis of the PostPC industry and the role Linux will play in its future as well as some steps to ensure the success of Embedded Linux. In order to properly understand the market, we first examine the background environment that will impact decision-making. This environment is composed of the prevailing mood and market conditions as well as an examination of the types of devices entering the market and the operating systems currently in the market. To examine the emerging trends in the PostPC market, we will look at how each of the hardware classifications’ needs are addressed by the RTOSes on the market, including Embedded Linux. We will also discuss general trends emerging in as the industry changes to meet the needs of the PostPC era. Embedded Linux’s potential will be properly assessed by examining the strengths that it exhibits as well as the challenges that face Embedded Linux. Finally, we will propose the actions that need to be taken to ensure Linux not only remains an attractive option for the PostPC Industry, but continues to gain popularity.

The remainder of the paper is organized as follows. In Section 2, we discuss the PostPC industry background. In Section 3, we analyze trends present in the PostPC market and in Section 4, we describe the outlook for Embedded Linux, the challenges it faces, and proposals to address these challenges. Finally, we conclude the paper in Section 5.

2. PostPC Industry Background

The PostPC industry background can be said to be composed of two important parts, the prevailing market and social conditions and the technological state-of-the-art. In the following sections, we will examine both of these aspects.

2.1. Prevailing Market Conditions
The prevailing conditions that have the largest impact on Embedded Linux are focused on market growth for PostPC industries. The PostPC industry has seen and will likely see continued strong growth, fueled in large part by the move towards ubiquitous computing as small devices become more powerful and wireless networking becomes more prevalent. Of course, this is a positive sign for Embedded Linux, as the industry as a whole grows the number of devices powered by Linux is bound to increase.

Competition from Microsoft should also be considered as a major influence on the success of Embedded Linux. While the embedded industry as a whole has expressed a general distrust of Microsoft and proven the strategies that brought Microsoft dominance in the desktop market unsuccessful, at least in the short term, this does not mean that they do not pose a significant threat. Even in the absence of broad industry support, Microsoft can still have the potential to dominate the market simply through the application of their huge resources over a sustained period. In addition, the conversion of the legions of desktop and server programmers familiar with the Windows operating systems to the similar embedded environments also gives a Microsoft-based platform a significant advantage.

2.2. Technology

The technological outlook for Embedded Linux is shaped by first, the devices that are in demand and second, the embedded RTOS available to run them. Table 1 shows a classification of PostPC hardware devices being brought to market now as well as examples of each. Table 2 enumerates the types of embedded RTOSes with examples of each.

In the following section, we will examine each of these hardware categories with the RTOSes that are applicable to each in order to paint an accurate picture of where the PostPC industry is headed.

3. PostPC Market Trends

In this section, we will explore the trends present in the PostPC industry. The first section will comprehensively examine the PostPC device categories and the RTOSes that power them and the trends for each. In the second section, we will look at trends in the traditional RTOS market and the impact open source software is having there.

3.1. PostPC Devices and Trends

*Platform Devices:* Microsoft’s embedded operating systems can be expected to maintain their strong showing due to a strong existing customer base and quality development tools. The performance strength over competitors that Microsoft once enjoyed will erode as competing platforms support devices with similar specifications to those supported by Microsoft. Linux’s success in this area depends largely on its ability to penetrate the desktop market. As long as the Linux interface remains unfamiliar to users, it will be a barrier to entry. Palm OS [12], which once enjoyed complete dominance over the market, has a difficult battle head of them to maintain market share.

*Network Devices:* Embedded Linux can expect to do well in mid-range devices where its protocol stack implementations give it an advantage over in-house development. In the low-end, one can expect in-house or traditional RTOSes to dominate these restricted environments. On the other hand, at the high-end, one can expect network-oriented RTOSes, such as IOS from Cisco [2], to be used because of their ability to address the need for high throughput and performance.

*Digital Consumer Electronic Devices:* Embedded Linux is expected to do extremely well in this area for larger devices. One can expect that only in smaller devices, such as MP3 players, will in-house kernels or traditional RTOSes be necessary to deal with stringent resource constraints.

*Ubiquitous Devices:* Ultra-low power and stringent resource constraints mean that these devices are likely to be powered by special purpose RTOSes. One-chip solutions and component-based OSes [1] for application-
specific hardware will meet the needs for these very demanding devices.

Hard Real-Time Systems: Traditional RTOSes can be expected to maintain their hold on this segment of the market. Linux might be expected to gain market share if it can satisfy the need for high pre-emptability, high availability, and low interrupt latency. If Linux were to gain some popularity on the desktop, one might see market share gained as developers become more familiar with Linux.

3.2. RTOS Trends

Recent trends have indicated that Embedded Linux is gaining market share throughout the embedded systems industry. Traditional, commercial RTOSes on the other hand have seen a declining growth rate. This decline is caused by, expensive royalties, a lack of standards between RTOSes, RTOSes not being suitable for complex system design, and a decline in interest on hard real-time systems, where traditional RTOSes typically dominate. Companies have been moving to address these concerns.

Wind River has acquired Berkeley Software Design Inc. and is now reselling BSD/OS as a general operating system and for embedded system development. QNX can now be freely downloaded and evaluated and Green Hill has made their RTOS royalty free.

Microsoft has been very dominant in the PDA market, capturing 60-70% of the Korean PDA market. It is now trying to move into the smart phone market, dominated by Symbian [11], which is owned by a consortium of the dominant phone manufacturers. Microsoft has had little success in this area and is not a particularly attractive option for network or consumer devices.

Also present in the RTOS market is BSD Operating System, a Unix operating system that is licensed under the BSD license, a license that is less restrictive than the GPL. BSD has excellent protocol stack implementations and a variety of specialized versions. BSD’s code is very well structured which makes it easy to analyze and quality development tools provide good time-to-market. BSD has been gaining market share as an open source alternative to Linux. As explained in the next section Linux shares many of these advantages.

4. Embedded Linux as an Embedded RTOS

In this section, we discuss strengths of Embedded Linux and the outlook for Embedded Linux. We will also discuss the challenges faced by Linux that need to be addressed in order for it to realize its full potential.

4.1. Embedded Linux Strengths

Linux’s gains in the PostPC industry are fueled by the convenience of Linux programming, as a Unix clone: Linux API programming is very similar to Unix. The open source licensing of Linux provides many advantages, the ability to customize and optimize at the source level, broad hardware support, low cost, and a large base of experienced programmers.

4.2. Outlook for Embedded Linux

In the market for general purpose platform devices, such as PDAs, Linux faces stiff competition from Microsoft and is unlikely to make significant progress in the market in the short term. Linux’s greatest potential lies in the market for mid-range network devices and consumer electronic devices. Not only is Linux already acknowledged as a good fit for these types of devices but it is also a center for much of the growth in embedded systems.

This does not mean that there are no concerns to be addressed with respect to Embedded Linux development. Rather, the following issues need to be addressed to ensure the broad adoption of Linux, even in these areas:

Reduce Total Cost of Ownership: Developing and maintaining Linux systems needs to be simplified to reduce the costs associated with using Linux.

Reduce Time-to-Market: Ensure that developers do not have to roll-their-own kernel for embedded projects.

Standardize Middleware: Make it easy to incorporate middleware components for different applications.

Tool-chain Improvement: Standard GNU tools are still not an attractive option when compared to many commercial options, such as Microsoft’s own tool-chain.

4.2. Proposals for Embedded Linux

To address key technical issues that will make Linux successful as a platform, we propose the following actions be taken:

The Standardization of a Core Embedded Linux Kernel: This kernel would provide a starting point for any embedded system, supporting ultra-fast booting, low-power API and device drivers, ultra-slim kernel, and built-in QoS and multimedia support.

The Standardization of Middleware: Middleware profiles available for different applications that can be plugged in to accelerate development.

The Standardization of IP and Component Exchange: A clearly defined forum for the exchange of standard components that can be plugged into the platform described above. This should involve a clear understanding of the terms of licensing and IP ownership by all parties involved in any transaction, ensuring that existing components can be leveraged with a clear understanding of the terms of use.
5. Conclusion

We have presented an overview of the RTOS market in the PostPC industry and the outlook for Embedded Linux in the future. We have surveyed the market conditions as well as evaluating the technology on the market today and how the devices of the PostPC era will use that technology. We also looked at what traditional RTOS vendors are doing to address the issues raised by open source alternatives.

What we found was that Linux is well positioned to be a strong competitor in the network device and consumer electronics categories as they best match Linux's strengths, allowing developers to take advantage of the robustness of Linux and having the flexibility to tolerate its relatively large size and resource demands.

We identified the weaknesses that need to be addressed in Embedded Linux and proposed a set of standardization initiatives that could be undertaken to create a standard Embedded Linux kernel, standard middleware profiles, and a standard for dealing with IP and components. We believe that these initiatives will make the already attractive Linux kernel a dominant force in the embedded systems market for the PostPC industry.

References

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