Survey of Operating Systems for the IoT Environment

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---ABSTRACT---

This paper is a comprehensive survey of the various operating systems available for the Internet of Things environment. At first the paper introduces the various aspects of the operating systems designed for the IoT environment where resource constraint poses a huge problem for the operation of the general OS designed for the various computing devices. The latter part of the paper describes the various OS available for the resource constraint IoT environment along with the various platforms each OS supports, the software development kits available for the development of applications in the respective OS'es along with the various protocols implemented in these OS'es for the purpose of communication and networking.

I. INTRODUCTION

The whole Internet of Things environment is based on the application of microprocessors and wireless sensors. The resource constraint environment of these microprocessors and sensors makes the use of regular OS'es meaningless due to their high resource and computing power requirement. Thus, in such a situation, the development of OS'es meeting the resource constraint demand of the IoT environment becomes necessary.

II. OVERVIEW

In section III the paper introduces the various aspects of an OS designed for the IoT environment. In section IV, the various OS'es available for running in the IoT environment along with a list of the supporting platforms, SDKs and the various networking and communication protocols implemented are surveyed. The paper is concluded in section V.

III. INTRODUCTION TO OS FOR THE IOT ENVIRONMENT

The whole integration of the various IoT devices to the various objects is made possible through the interaction of software at a dynamic level along with the use of wireless sensor network and RFID technologies using the internet infrastructure ([1], [6]). This software interaction is made possible through the operating system running behind the scene within each IoT device without which an IoT device would be nothing more than a non-functioning device. The flexible features of the various operating systems of an IoT device has facilitated some interesting integration of electronic products and technologies to the daily processes of an individual thus making the processes a whole lot easier to use and access. Some out of the multitudes of IoT technology integration and innovations are smart light bulb ([28]), implementation of real time passenger information system ([22]), smart tags/NFC tags ([17]) etc.

The OS'es developed for the IoT environment require very few kilobytes of RAM as well as operate with low power consumption. Moreover they are specifically designed and optimized for a particular set of microprocessor-based platforms beyond which such OS'es becomes irrelevant in its application ([38]). These OS'es do not compromise in terms of features relating to communication, networking, security etc. as compared to the regular OS'es like Windows OS, Mac OS etc. but comes built-in with a number of pre-installed, pre-integrated applications, drivers and other network protocols. Moreover these OS'es employ a number of unique security measures for enhancing the IoT

infrastructure as a whole and to avoid the compromise of the stability and usability of the OS.

Though the security issues of the OS'es for the IoT environment are quite different in comparison to the security issues of a regular operating system, yet it still retains the standard security protocols for protecting itself against unwanted attacks. Now the IoT environment is made in such a way so as to carry out information exchange between the various electronic devices over the internet in the most efficient way possible using the lowest amount of resources. As such the whole IoT environment along with its OS becomes prone to malicious attack from the third party intruders. So the successful implementation of various encryption and data hiding techniques ([4], [5], [12], [15], [39]), intrusion detection systems ([16], [33]) etc. in the IoT infrastructure takes a paramount importance.
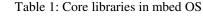
[45] takes care of sleep deprivation attack blockage on IoT elements, to preserve their already fragile power resources.

IV. OS'ES

i. mbed: Developed by ARM in collaboration with its technological partners, mbed OS is developed for 32-bit ARM Cortex-M microcontrollers ([29]). The whole OS is written using C and C++ language. This open source OS is licensed under Apache License 2.0.

The software development kit (SDK) for mbed OS provides the software framework for the developers to develop various microcontroller firmwares to be run on IoT devices. These SDK is comprised of core libraries which consist of the following components given in Table 1:

Networking	Test scripts	Microcontroller peripheral drivers	RTOS and runtime environment	Build Tools	Debug Scripts

Table 1: Core libraries in mbed OS

The applications for mbed OS can only be developed online using its native online code editor cum compiler known as mbed online integrated development environments (IDEs). While writing of code can only be done through a web browser, its compilation is done by the ARMCC C/C++ compiler in the cloud.

In the connectivity front, the mbed OS support the following connectivity technologies given in Table 2:

Bluetooth Low Energy	Wi-fi	Zigbee IP	Zigbee LAN
Cellular		Ethernet	6LoWPAN

Table 2: Connectivity technologies in mbed OS

mbed OS integrates end-to-end IP security (IPv4 and IPv6) through TLS and DTLS in its comm. channels for increased security of the whole OS environment. Moreover for management of various devices in its environment, mbed OS uses OMA Lightweight M2M protocol.

ii. RIOT: Developed by INRIA, HAW Hamburg and FU Berlin initially, RIOT OS is compatible with ARM Cortex-M3, ARM Cortex-M4, ARM7, AVR Atmega and TI MSP430 devices ([8], [24], [31]). Developed using C and C++, this open source OS is licensed under LGPL v2.1.

The SDKs available for development of applications in RIOT OS are gcc, valgrind and gdb. Moreover the SDK framework supports application programming in C and C++.

RIOT OS supports all the major communication and networking protocols which are tabulated in Table 3:

IPv6	6LoWPAN	RPL	CoAP
UDP	TCP	CBOR	CCN-lite
OpenWSN		UBJSON	

Table 3: Networking protocols in RIOT OS

iii. Contiki: Created by Adam Dunkels and further developed by people from various organisations and institutions like Atmel, Cisco, ENEA, SAP, Sensinode, Oxford University etc. ([3], [19], [35]), the Contiki OS is aimed to be used in various microcontroller devices which are tabulated in Table 4:

Atmel ARM	Atmel AVR	STM32w	TI MSP430
TI CC2430	TI CC2538	TI CC2630	TI CC2650
LPC2103	Freescale MC13224	Microchip dsPIC	Microchip PIC32

Table 4: Microcontroller devices running on Contiki OS

This open source OS is licensed under BSD License.

The programming model of the Contiki OS is based on protothreads for efficient operation in resource-constrained environment.

The Contiki OS features Cooja, a network simulator which simulates Contiki nodes ([18]). These Contiki nodes are of three types:

a.   Emulated nodes
b.   Cooja nodes
c.   Java nodes

The various networking protocols supported by Contiki OS are given in Table 5:

CoAP	6LoWPAN	RPL

Table 5: Networking protocols in Contiki OS

The Contiki environment is generally made secure through the implementation of ContikiSec ([21]) and through the implementation of TLS/DTLS ([9]).

iv. TinyOS: Developed by TinyOS Alliance, this open source OS is mainly developed for wireless sensor networks ([2], [7]). It is written in nesC and is licensed under BSD License.

The SDK for application development for TinyOS is comprised of the following three IDEs:

a. TinyDT

b. TinyOS Eclipse Plugin "YETI 2"

c. TinyOS Eclipse Editor Plugin

The various communications and network protocols implemented in the TinyOS are given in Table 5:

Broadcast based Routing	Probabilistic Routing	Multi-Path Routing
Geographical Routing	Reliability based Routing	TDMA based Routing
Directed Diffusion		

Table 5: Communication and networking protocols in TinyOS

The whole architecture of the TinyOS has been made secure over the years with the implementation of TinySec ([44]) and various types of embedded security layers ([13], [14], [30], [40]).

v. Nano-RK: Developed at Carnegie Mellon University by Alexei Colin, Christopher Palmer and Artur Balanuta, Nano-RK is specifically targeted for running in microcontrollers (presently runs on MicaZ motes and FireFly Sensor Networking Platform) to be used in wireless sensor networks. Nano-RK OS is written in C language and is open source ([10], [43]).

The application development of Nano-RK OS is supported by the Eclipse IDE.

The communications within the OS is carried out with the help of the following protocols given in Table 6:

RT-Link	PCF TDMA	b-mac	U-Connect	WiDom

Table 6: Communication protocols implemented in Nano-RK

vi. FreeRTOS: Developed by Real Time Engineers Ltd., the FreeRTOS is developed for platforms listed in Table 7:

ARM7	ARM9	ARM Cortex-M3	ARM Cortex-M4
ARM Cortex-A	RM4x	TMS570	Cortex-R4
Atmel AVR	AVR32	HCS12	Altera Nios II
MicroBlaze	Cortus APS1	Cortus APS3	Cortus APS3R
Cortus APS5	Cortus FPF3	Cortus FPS6	Cortus FPS8
Fujitsu MB91460 series	Fujitsu MB96340 series	Coldfire	V850
78K0R	Renesas H8/S	MSP430	8052
X86	RX	SuperH	PIC
Atmel SAM3	Atmel SAM4	Atmel SAM7	Atmel SAM9

Table 7: Platforms supporting FreeRTOS

Written mostly in C with the addition of a few assembly functions, this open source OS is licensed under Modified GPL ([25], [26]).

The application development part for FreeRTOS is handled through multiple threads, software timers and semaphores along with a tick-less mode for low consumption of resources by the running of the various applications.

V. CONCLUSION

From the above survey it can be seen that all the OS'es for the IoT environment are well equipped with all the major networking and communication protocols, security features as well as optimized for efficient usage of computing power in a resource constraint environment. Yet the additional implementation of counter measures to online dictionary attacks ([11], [20], [32]) in the internet infrastructure used by the IoT environment with the additional emphasis on developing a more robust wireless sensor network ([27], [34], [37], [41]) will contribute to the protection of user's credentials during online transactions ([23], [36], [42]) logging inside one's personal account in the cloudand will make the whole IoT environment much secure and more reliable.

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