Intelligent Low-Power Displaying and Alerting Infrastructure for Smart Buildings

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Abstract. The paper presents the architecture of an intelligent displaying and alerting system, based on a scalable integrated communication infrastructure. The system is envisioned to offer dynamic display capabilities using the wireless ePaper technology, as well as to enable indoor location-based services such as visitor guidance and alerting through iBeacon-compatible mobile smart devices. The system will include a secure web management console, along with the software interfaces and procedures necessary for collecting and automatically displaying any relevant information and notifications. As the system is designed primarily for educational and research institutions, remote authentication will be allowed through eduroam technology. Tests regarding the performance of the used wireless ePaper Displays are performed, specifically regarding their response times, and recommendations are made based on the results.

Keywords: ePaper · iBeacon · Alerting system · Indoor positioning
Low power display

1 Introduction

The emergence and continuous development of new communication and display technologies with low power requirements has opened new opportunities in creating a sustainable infrastructure for digital room signage for conferences, meeting rooms, or even modern office buildings. The new focus on electronic, digital technologies, rather than the use of paper, simplifies the management of displayed information. For example, the effort of manually changing thousands, or tens of thousands of paper-based labels can be transferred to a scalable digital display system, with tens of thousands of screens connected to it; as a result, countless man-hours of work can be saved, while also reducing the time required to update all paper labels.

The new low-power display solutions rely on the electronic paper (ePaper) technology, while the low-power wireless communication is based on the Bluetooth Low Energy (BLE) technology, along others like it. Recent advances in the field of monitoring networks of sensors have been marked by the emergence and integration of new technologies, like the above, in the field of Internet of Things (IoT) interactions.

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The paper proposes an intelligent displaying and alerting system (SICIAD) that relies on the wireless ePaper and iBeacon technologies [1] in order to provide a framework for displaying both static and dynamic information, as well as to ease the indoor orientation of guests. At the same time, the system aims to provide real-time alerting facilities for emergency situations (including the case of having to direct the evacuation of entire office buildings).

The system's primary objective is to build on the existing technology and simplify its use, in order to provide the custom automatic update of all displayed information, in a secure fashion. SICIAD is primarily designed as a display and notification framework for public institutions like universities and government buildings. However, its applications may include public transport companies, airports, expositions and commercial centres, museums or even indoor and outdoor amusement parks. Any organization that relies on conventional paper-based (or even digital) signage can, in fact, benefit from the use of a centrally-managed low power display system.

The paper's content is organised as follows: the Sect. 2 provides some background information regarding the wireless ePaper technology, while Sect. 3 presents the architecture, design considerations, and several implementation details of SICIAD. Section 4 presents the preliminary evaluation results for the system, while the final section draws the conclusions.

2 Wireless ePaper Technology

The electronic paper (mostly referred to as ePaper or sometimes e-Ink) can be seen as a display medium with memory, one that can be re-written multiple times in order to display various content. Therefore, the concept of ePaper can be defined as a display technology that simulates the appearance of text written on a traditional physical paper [2].

The technology relies on ambient light reflection instead of a backlight, as well as a screen that requires a significant amount of energy only during the update phase, along with a near-zero power consumption [3] in the idle phase. Such digital displays offer good visibility of information in all light conditions, with the benefit of a low power consumption.

Today's applications of ePaper displays include electronic shelf labels, digital signage, time schedules for public transportation, billboards, portable signs, although some of their first wide-scale commercial applications were electronic newspapers and e-book readers.

However, because these technologies are still relatively new, their use requires extensive computer programming skills to access and manage the displayed information. As we stand, the current level of technology relies on the user either micro-managing individual displays, or writing complex scripts for the dissemination of multiple information flows and dynamic update of these displays.

Currently, there are several companies that offer tools for digital room signage. All these solutions are generally comprised of three components:

- the display panels, based of ePaper technology, or other technologies like LCD (Liquid Crystal Display) or LED (Light-Emitting Diode) and their variants;
- the wireless communication infrastructure, which can be based on BLE, ZigBee, GSM (Global System for Mobile communications), WiFi, or even the newer addition to the field, LoRa;
- the content management system, for the signage infrastructure.

SICIAD is envisioned to take the place of the third layer in the above system, as a manager for the ePaper labels and the information being displayed on them. The first two layers are based on the wireless ePaper technology provided by Lancom [4].

The wireless ePaper solution functions on 2.5 GHz radio channels, in the same frequency spectrum as WiFi or Bluetooth, but on much smaller channels. The displays are controlled through special WiFi Access Points, designed specifically to integrate the wireless ePaper communication technology, and all control and data information flows pass through a software ePaper Server [5]. Moreover, since the platform is designed for low-power applications, covering large office spaces will require the use of several access points, configured on different wireless ePaper channels in order to avoid interference.

Lancom's ePaper Server software offers complete access to all management and signage functions through an XML (eXtensible Markup Language) API (Application Programming Interface), including ePaper monitoring and operation, alongside the signage API. The interface permits directly uploading binary image information (encoded in the Base64 format), as well as generating it through the integrated image render and a set of image templates.

At the same time, the manufacturer offers a small number of tools, capable of extracting singular information from external data sources, such as Google Calendar or Office365. Complex interactions, such as the ones described in the current paper, require a more complex management software, described in the following sections.

Complete information regarding the performance of ePaper displays, most notably the time required to display an image, is still unavailable from most manufacturers. Even from the used platform, the manufacturer only provides relevant information related to the lifetime of the display's batteries: around five years, as long as the displays are updated no more than twice every day [4], for the three-colour, red, black and white displays. Other manufacturers indicate display times between 3 and 8 s for black and white displays, and 15 or more seconds for three colour displays of similar sizes [6]. Older research also shows response times in the order of seconds, for ePaper display technology [7]. More information, including results of performance tests on the wireless ePaper devices, will be found in Sect. 4.

One key functionality consists of the fact that the users can remotely update the displayed content in real time. To allow a highly flexible use, the wireless ePaper displays eliminate the need for an external power supply or a physical network connection due to the fact that the devices are battery powered and radio controlled. Furthermore, the data transmission process can be protected by a 128-bit key, allowing secure encryption and authentication standards for eduroam [8, 9].

3 System Architecture

SICIAD is meant to capitalize on recent developments in the field of digital room signage, using Bluetooth Low Energy (BLE) for indoor-positioning services, as well as wireless ePaper devices for remotely displaying information. The project's main objective is to provide an integrated system for the dynamic display of information in educational and research institutes. At the same time, the system aims to provide the automatic display of notifications and alerts, in order to aid in the emergency evacuation of covered spaces, should the necessity ever arise.

The system aims to integrate the Lancom wireless ePaper solution, described in the previous section, in order to dynamically display information and provide notification on certain events. For this, it proposes the development of an integrated management application for the infrastructure and wireless ePaper displays, along with the software interfaces to integrate information from multiple external data sources. The general concept of the target system is described in Fig. 1.

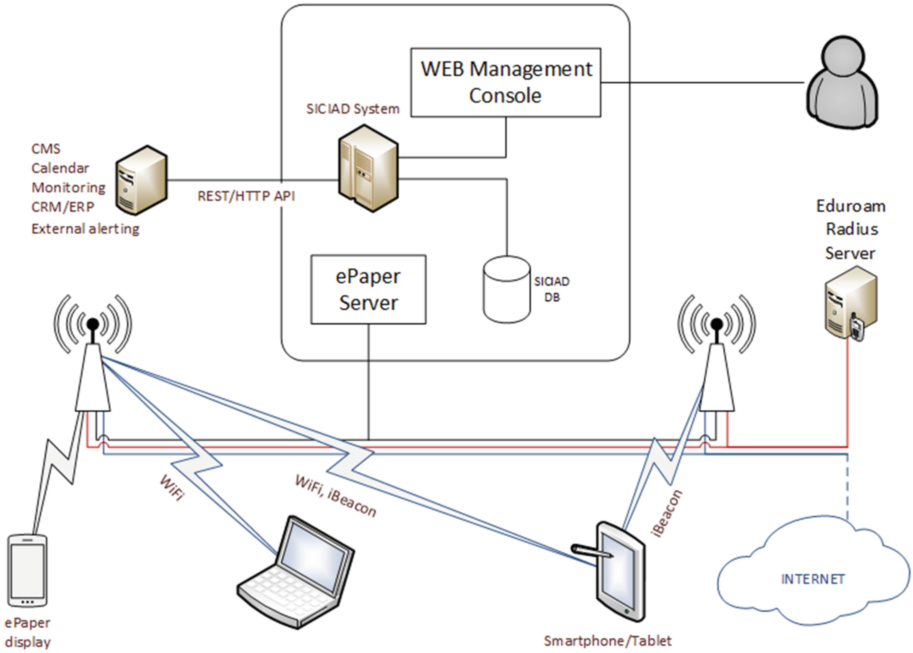

Fig. 1. Concept for the low-power displaying and alerting infrastructure

The framework provided by Lancom includes the wireless ePaper-enabled access points, capable of providing internet access to the communication systems covered by them, as well as of controlling the configured ePaper displays. All ePaper displays are controlled by Lancom's ePaper Server software, which enables user interaction through its XML API.

The use of wireless technology simplifies the deployment of the system, since additional wiring or power sources will not be necessary. However, several facts should be mentioned.

First off, the ePaper displays (including the Lancom ePaper displays proposed for use in the system's architecture) are designed to work at a low level of power consumption. This means a slow refresh rate of the displayed information, when changes occur. For static information, this is not an issue: all the displays can be updated in the off hours, when no one is using them. However, an issue may arise when trying to display urgent dynamic notifications, like an emergency evacuation alert. For such cases, further study is needed regarding the wireless ePaper response time.

The specifications of Lancom ePaper displays indicate a battery life time between 5 and 7 years, if the displayed information is changed four times a day [4]. For more interactive applications (like the first use case), or improving response times for emergency situations, additional power sources may be needed, which may come in the form of solar panels in outdoor deployments, (when battery replacement may become an issue).

Secondly, the Lancom Wi-Fi Access Points integrate iBeacon technology. This offers a simple means of determining whether a mobile smart device is in close range of the access point, but a larger iBeacon network is necessary for determining exact indoor position. As such, further work may relate to the integration of stand-alone iBeacon devices in the SICIAD architecture.

The Server's interfaces, from the project's point of view, are described in Fig. 2.

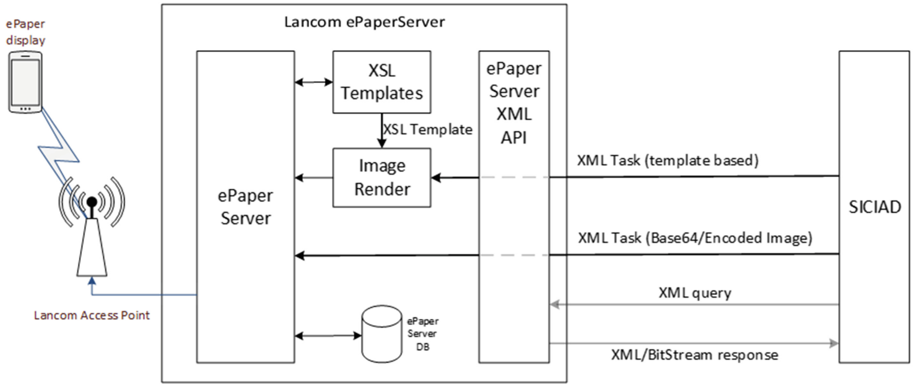

Fig. 2. Lancom ePaper Server XML API

The ePaper Server offers the ability to remotely configure, monitor and control the wireless ePaper devices, offering complete status information regarding all connected access points and displays, alongside information regarding the status of all previously executed tasks. All commands to display information on the ePaper displays are issued in an XML format, either with Base64 encoded images pre-rendered by the issuer (user) to exactly fit on the desired devices, or using an internal rendering engine. The server's own rendering functionality allows images to be generated, based on a set of XSL (eXtensible Stylesheet Language) templates. All information, including generated images, task status changes, monitoring data, is stored in the server's internal database and available through the XML API.

Based of the above-stated objectives for the system, as well as the wireless ePaper system's features, the following three general use cases for the system have been determined:

1. **Dynamic display system** – which updates the ePaper devices based on a set predefined rules, either automatically or at the user's request,
2. **Visitor guidance system** – relying on BLE iBeacon emitters to pin-point the users' locations and provide indoor navigation assistance and location based services, and
3. **Dynamic alerting system** – relying on components from the previous use cases and superseding their displayed/broadcasted information. In case of an alert, the system will store the previous normal running state and, once the alert has passed, restore it.

The BLE-based indoor visitor guidance facility will not be discussed in the current paper, as it is not within its scope.

As previously stated, the system aims at the development of an intelligent system that can dynamically display information and provide notification on certain events. For this, it proposes the development of an integrated management application for the infrastructure and wireless ePaper displays, along with a software interface for connecting to Internet calendar or other cloud services, several access levels and e-mail message programming. The proposed architecture for the SICIAD system, based on the above observations, is described in Fig. 3.

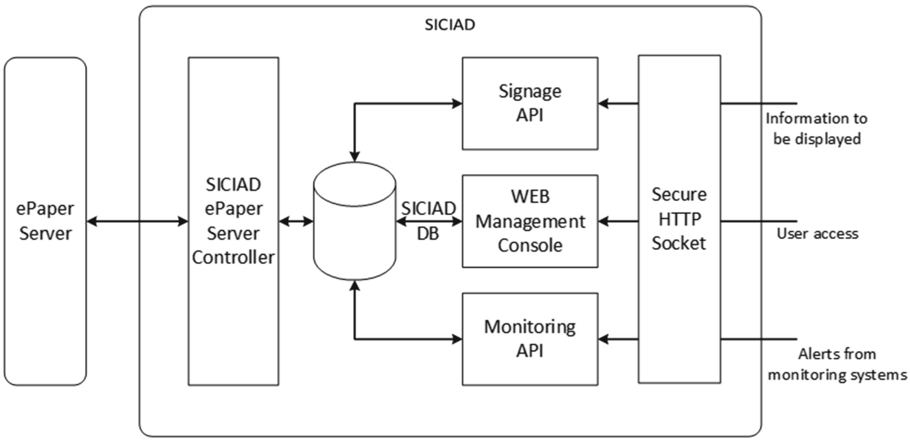

Fig. 3. SICIAD architecture

The task of communicating with the ePaper Server, retrieving all pertinent information through the API, as well as issuing display commands for the wireless ePaper devices will fall to the *ePaper Server Controller*. The software module will function as a background task, continuously checking for any information changes. A specific use-case for the module will be to control the display of alerts in case of emergency situations. For that to correctly function, it must store complete status information regarding the labels. Should an emergency situation appear, all other displayed information will be overwritten (since the displays have a memory of up to 12 pages, one or two can be reserved for alerts, separating the two operation modes). Once the emergency situation ends, the system will revert to its normal operating mode.

The *Signage API* will function as an endpoint for any external data flows of information, while the *Monitoring API* will receive data from monitoring systems or IoT sensors (temperature, CO2, smoke, gas) to identify threats, send alerts through its available means, or even automatically initiate emergency evacuation and facilitate the avoidance of problem areas and to provide guidance towards safe exits (including aid for the hearing impaired). All status information will be stored in SICIAD's internal database.

Finally, the *Web Management Console* will enable the dynamic display of information, either on ePaper devices connected to the infrastructure and without wired power supplies, or on the users' cell phones, using beacons based on the iBeacon technology. All modules, including the management console and the API will be secured in order to prevent unwanted intrusions in the wireless signage system.

Currently, of the above components, most of the ePaper Server Controller, along with a portion of the management console, have been implemented, allowing several performance tests on the ePaper devices to be performed.

4 Preliminary System Evaluation

Several tests have been performed in order to determine the delays that occur when updating the information on the ePaper displays from the wireless ePaper server. To that end, two L-151E access points were used together with one WDG-1 7.4″ ePaper display. The Access Points were registered to a remote ePaper Server installed on a openSUSE Linux machine. Current version of LANconfig was installed on a virtual Windows Server 2013 machine, in order to be able to configure the Access Points, register and update ePaper displays.

In a first experimental test scenario, the delay of changing ePaper content was determined for simple operations, such as image delete, change, rotate and show ID. The results are summarized in Table 1:

Table 1. Common operations and corresponding delays

Operation	Details	Delay [s]
Delete	Delete image	330–473
Change	Change image 480 × 800 (7.4″)	27
Rotate	Image rotation	2
Show ID	Show label display ID	14

The primary issue with ePaper display testing has been battery longevity. As previously mentioned, the devices consume significant amounts of power when performing operations (displaying new images). In order to limit battery use, each test was performed with only a small batch of operations. The tests have been conducted with

Lancom's Wireless ePaper management software, as well as a first-stage version of SICIAD's management console, capable of sending XML tasks to the ePaper Server.

Because ePaper displays communicate on a wireless channel, interference with nearby radio networks has been noted, and several test results (with extremely large values) have been excluded. During testing, it has also been noted that if two Lancom access point operate on the same wireless ePaper channel and are within reach of the same ePaper display, they will interfere with each other, increasing task execution times, or even preventing it.

However, the first test only offers a limited view of Lancom's Wireless ePaper platform. To test its viability against the above use cases, images varying in size (from less than **1 KB** to over **200 KB**) have been uploaded, and the execution times for each *image display*, *preload* and *switch* operation has been recorded. The main concern in this scenario is determining whether it is possible to display emergency alerts on wireless ePaper displays, within the use cases' time constraints.

The results are shown in Table 2, and include the wireless average transmission time, as well total task execution delays. Excluding extreme values, average Image display time of **14** to **20** s has been obtained, with usual execution times not exceeding one minute.

Table 2. Display and preload operation delays

Operation	Avg. transmission time (s)	Delay [s]		
		Min	Avg	Max
Image	1.6	1.6	14.47	46.21
Preload	1.8	1.8	16.42	23.50
Switch	0.059	0.059	20.84	49.50

Analysis of the dependency between the image transmission time (on the wireless channel) and image size, suggests that small images (less than 100 kB), optimized for B/W ePaper devices, could be transmitted in less than 2 s. In the absence of radio interference, such images could load in less than 30 s.

Based on these tests, it can be said that an average **15 s** delay may be deemed acceptable for displaying alerts on single devices. However, when working with significant numbers of wireless displays, the response times may rise to unacceptable levels (several minutes if only the average case is considered, tens of minutes in the worst-case scenario).

In order to respect the constraints of displaying emergency alerts, the messages can be preloaded on the displays and then the system can use a more rapid switch operation (which only takes a fixed **59 ms**, a short enough time to avoid errors due to radio interference).

Further testing on the wireless ePaper display side will focus on the relationship between transmission power and transmission time, along a more accurate estimation of the relationship between image size and transmission time/total duration. At the same time, future tests will attempt to determine whether it is possible reduce transmission time even further, through use of the ePaper image rendering system.

5 Conclusion and Future Work

The paper presents a displaying and alerting system, based on an integrated communication infrastructure. The system offers dynamic display capabilities using the ePaper technology, as well as enables indoor location-based services such as visitor guidance and alerting using iBeacon-compatible mobile devices.

Starting from the system's architecture (described in the third chapter), most of the ePaper Server Controller has been implemented, enabling several performance tests of the used display devices.

Measurements taken in the evaluation phase show that the ePaper displays' response times are relatively short, being suitable to proposed use cases. Tests show that the largest delays are obtained in the case of deleting images. However, further study will be needed to guarantee rapid response times in case of emergencies.

A production installation of the system would consider avoiding tunnelling between ePaper server and Access points, by collocating all the components of the systems in the same LAN, in order to exclude extra delay and other potential issues introduced by the tunnelling technique. In such a case, availability and performance would improve.

The batteries provided by the manufacturer for the ePaper displays are sufficient for most of the use cases, whilst being easy to replace for indoor applications. For outdoor applications, ePaper systems can be recharged via solar cells and, due to their low power consumption, may function entire seasons without sunlight, offering a long-term solution for displaying information in remote areas.

Future work with the project will include the development of the system's web management console and signage and monitoring APIs, along with the further investigation of ePaper response times and iBeacon functional range, as well as the proposed architecture's scalability, performance and security.

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