Wireless Technology for Electronic Shelf Label System

With the strong online sale growth, retail stores in your neighborhood are facing strong competition from virtual world, mainly the competitive pricing and merchandise variety. Increased worries about internet fraud and personal data leak and the unreplaceable “non-virtual” shopping experience still give the reality store a good reason for consumer to keep shopping there. How to improve the logistics and the pricing gap are very important for future retailers to keep customers coming through the front door. Electronic Shelf Label, also known as ESL, is a system used by stores for quickly displaying product pricing on shelves to address the “dynamic pricing”: imagine thousands of store fronts receive the immediate pricing adjustment from headquarter sale meetings, and millions of price labels are changed in tens of minutes, just as those online stores do every day. Customized promotion (timely or location), exchange rate reflection, shopping cart advertisement, and many other new marketing strategies can be made possible. ESL equips retail stores with a new weapon to fight the battles with the virtual stores (and to each other). This is the reason why many retailers seek for ESL solution these days.

Why radio? How is it different from Infrared (IR)?

Until today, diffused infrared is one of the major ESL wireless technology choices due to its advantage of low tag cost. The wireless link is established by infrared bounced off surfaces. The transmission speed compromise due to reflection is compensated by the data compression, and “two-way” link is possible if the receiver confirmation is made simple. Since it still uses the “light”, transmitter installation (at the store ceiling) is costly and critical for good coverage, and the store island movement may lack flexibility after the system is in place.

On the contrary, radio-frequency (RF) wireless solution is more flexible and immune to the blockage such as light, human, shopping cart, and so on. The base station installation can thus be less hassled when it comes to the sale floor shelf re-arrangement. Through the right frequency selection, radio interference with 3G

Figure 1: Segment LCD vs. Graphic Price Label

At the outside, ESL tag is an electronic display device attached to the front edge of store shelf. The display could be the cheesy Liquid Crystal Display (LCD) or high-quality e-Paper (used in Kindles) panel. At the Inside, a wireless communication module allows the price display to be automatically updated through the managed network whenever the display information needs to be changed. This network can be formed using radio, infrared or even visible light communication.

An automated ESL system can passively reduce the management labor costs or actively (most difficult yet important) improves pricing accuracy and efficiency. Huge differences reside behind wireless communication technologies for ESL. Wrong choice may immensely impact the cost, the use model and result.
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or Wi-Fi can be avoided because different “channels” can be utilized to handle data stream: an efficient communication protocol can streamline packets delivery to enable high-speed wireless link: up to 10,000 full matrix-label updates per hour has been shown with ESL system using ISM license-free band. Inspired from cellular technologies, M2C RF ESL can interactively exchange information between base station and tag. This means IT department can closely monitor the tag status and even actively collect information. Since the infrastructure is similar to cellular network, it is also scalable to the different sales floor size, and so is the installation cost.

Radio frequency selection

Low-frequency (LF, up to hundreds of KH) RF solutions, although attractive for very simple tags, have many drawbacks. They include very low data rate that makes showing complex graphics a greater challenge than segmented image; band co-existence issues which is not easy to work around as the frequency is too low to allow multiple channels; regulatory hazard as the band may be shared with Low-frequency RFID devices and also certain long-range military communication; security concerns since ciphering is not applicable to such a low data rate; and the RF signal may go well beyond the target site with its wavelength in kilometer ranges.

On the opposite is high-frequency RF such as the popular 2.4GHz Zigbee or BLE. Although their data rates are more than enough to handle ESL applications and provide security, they suffer from Wi-Fi coexistence in the same band, with limited range and less reliable transmission: the higher the frequency, the shorter the distance it can cover, and the more sensitive it becomes to blocking. Although looking initially attractive, these solutions may not live to the expectations of battery life, scalability, and coverage. M2C’s wireless communication protocol Platanus is using sub-GHz RF, which shares some DNA with proven cellular technologies like GSM, and realizes a perfect trade-off for ESL application, allowing a good coverage for an ESL site such as a retail store, reliable secure transmission and sufficiently high data rates to allow lots of multicolor e-paper displays to be updated instantly. Fundamentally sub-GHz is also more power efficient than 2.4GHz: Friis equation shows the path loss of 2.4GHz radio wave is higher than 900MHz radio wave by 8.5dB:

\[
\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2
\]

P_r means receiving power and P_t means transmitted power. The result is the same power output using 900MHz will yield 2.67-time transmission distance compared to 2.4GHz.

Low power is the key

Major retailers require the ESL tag to have minimal 5-year lifetime without changing batteries (and they do care how many batteries you need to use): most ESL installation requires around 24 to 36-month payback time, so 60-month lifetime is reasonable but a rather tough challenge for any commercially-available radio technology. This is why Infrared
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technology and passive RFID are still largely used in ESL thanks to their relatively low-power advantage in comparison with alternative communication technologies. With increased data flow and complexity, solutions using _active-RF_ technology are sought more than ever. It has been proven that more than 5-year battery life with a single coin-cell battery can be achieved for ESL, supporting unparalleled data reliability and flexible display thanks to M2C’s innovative communication protocol.

The key aspect impacting device power consumption is the networking behavior: the mid-sized store front could have a tag count of 4,000 to 6,000 pieces. This posts a tough challenge for any “two-way” RF network: data packets transmitted by one device can collide with those by other devices using the same radio channel. When device count increases, the collision exponentially increases so the data throughput is compromised due to increased transmission failure. This is similar when more data are transmitted wirelessly, i.e. picture instead of text. Contrary to what one might think, use of low-data-rate wireless node extends air time which increases the collision possibility, leading to higher average power drainage. In general, there is a trade-off between data throughput and battery life: the higher the data throughput the less the battery life, and vice versa. Having resolved this issue, M2C’s Platanus protocol smartly allocates the RF resources to minimize the inefficiencies, so the power consumption can be relatively independent of the network size.

**One-way, two-way and interactive**

It is worthwhile to mention that when “broadcasting” (like FM) is used, the network size becomes less of a concern. However, without knowing if the tag has received the correct data can be a nightmare for retailers since customer may pay the price of a pencil to buy the whole golf set! In reality there is never an “error-free” channel: it is all about probability. Typically wireless is much worse than wired channel since the media is dynamically changing, i.e. people walking by, floor light blinking, and so on. Logically when more complicated data is transmitted, “confirmation” (not just “got it”) is highly recommended. If your ESL vendor tries to convince you that their tags will not make mistakes whatsoever, think again. Without that capability, retailers have to send someone to the label to check that it updated properly. And why pay for such an expensive ESL system that simply automates existing processes but still requires a manual check of the new, automated system? It is not good business practice because it incurs extra expenses, disrupts operations, requires employee training and there is little, if any, material gain.

**Interactivity** is often required for a reliable wireless link. It should be noted that “two-way” is different from (and inferior to) “interactive”: as an example, high-powered Infrared transceiver installed on ceiling may be able to deliver complicated data, yet shelf tag may only blink “got it” to acknowledge, for the sake of saving battery power. Yet this is only “two-way” but not “interactive”. There could be many useful tag informations like battery level, tag...
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temperature, call button, self-diagnose results, etc., and they are useful for the retail stores if “interactive” technology is available. The trade-off is power consumption and that may be solved by protocol and chipset in modern RF technology, like in M2C’s offering.

Economy LCD vs. high-quality e-Paper

Until now segmented LCD is the most common ESL display these days. Nevertheless, thanks to its low power consumption, display technologies with bi-stable feature have become an emerging and promising choice. Used in Amazon’s Kindle e-book device, E-ink’s e-paper has gained great popularity over the last few years. With the release of the triple colors product Spectra which would improve the viewing experience and enable new features for ESL, the dynamics between a high quality yet more expensive e-Paper and low quality LCD may gradually be changed.

One of the advantages of e-paper is that high resolution graph can be shown on e-paper, with unparalleled readability of any character set (Latin, Chinese, Kanji, Korean, Arabic, etc.) with flexible outline (e.g. bold, italic, underline, white-on-black, white-on-gray, red-on-black). Structured information like logos, 1-D barcodes and 2-D QR codes can be accurately reproduced, enabling easier, cheaper and more popular ways of interacting with consumers than with more complex technologies like the NFC, which is not and may never become commonplace for smartphones. As part of the “intelligent” shelf labels, full-matrix graphic ESL with robust radio gives a great flexibility at logistics and marketing. Since more complex information will be shown on these tags (i.e. up to 75kbits for a 2” E Ink 3 colored graphic ESL), data rate becomes a concern for wireless communication.

The classic Nyquist-Shannon sampling theorem states that data rate carried in the digital communication cannot be higher than 50% of its carrier frequency. For example, for 36kHz radio carrier, no more than 18kbits/s physical transmission can be achieved. In practice, much less spectrum allocation is available at these low frequencies due to the regulatory restrictions which are, further, not harmonized worldwide. The lower available data rate may still be sufficient for segmented display, but will face great challenge in power consumption and transmission time when handling graphic tags showing complicated interactive content.

Most wireless technology delivers data in a series of “packets”. Packets are usually made short to minimize the over-the-air corruption, i.e. 40 bytes. When longer data is to be sent, multiple packets need to be sent and concatenated. Cyclic Redundancy Check (CRC) is needed to ensure the received data is correct,
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and the results need to be reported back to the transmitters to decide if resend is needed. In the ESL network, thousands of receivers are present but the packet only goes to one while others may be in sleep mode to save power. How to avoid waking up others becomes critical to achieve high power efficiency. It is worthwhile to mention that some off-the-shelf protocols, such as Zigbee, may suffer from the unexpected behaviors (such as traffic holdup, exposed/blind spot ...), leading to excessive power drain under network size variation. M2C protocol Platanus efficiently solves these issues for the profiles defined for ESL applications.

Microcontroller (MCU): 8-bit vs. 32-bit
When only displaying images on e-paper panel, cheesy 8051 MCU may be more than enough. Unfortunately when it comes to handling the thousands of wireless nodes, it is definitely crippled. A 32-bit MCU offers ample computation power to handle both the signal processing (i.e. image, ciphering) and networking tasks. With its prices dropped to reasonable range, 32-bit MCU becomes a better choice for ESL. With over 10x processing speed for 32-bit vs. 8-bit MCUs, ESL tag can quickly finish the designated task and enter the sleep mode to lower power consumption.

When handling the wireless physical device, i.e. RF transceiver, a good portion of power consumption may come from MCU since ISR (interrupt service routine) needs to monitor and control the external chipset the whole time. This can cause unexpected task interruptions and unnecessary power waste. Also, programmers need to carefully allocate the MCU resources as suited. System-on-chip will have benefits in shortening the data processing path between MCU and transceiver, but users need to watch out for the built-in constraints between MAC and PHY layers. This information was often not released by chip vendors, though.

With a powerful low-power MCU, combined to a smart protocol, M2C’s Platanus improves battery-life and efficiency in ways that are often overlooked when selecting a solution, like the capability to update only parts of the display (i.e., only the price) to cut the transmission time by 75% or more, or the possibility to seamlessly update the firmware of the tags within M2C Platanus - with no loss of connectivity - to enhance their features or fulfill special temporary requirements to support the sales (special display for special offers, blinking label, change of button use, etc)

To further optimize the power consumption, glue logic can be used to assist some routine tasks to minimize the MCU activities. For instance, ESL solution often uses lossless image compression to increase the data throughput. A customized hardware design can efficiently take care of the compression faster and with less energy by not involving the MCU at all. Another example is the address-filtering, where wireless nodes do not need to wake up MCU if the packets are not meant for them to process.

Looking at the right power parameters
When selecting the wireless chipset for ESL, people are often looking for the lowest of everything: floor current, RX, TX, and so on. But how low is enough? Assuming there were this...
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magic chip, is it guaranteed that it will deliver the best result? The answer is not that simple.

When it comes to the battery life, battery capacity is considered, and it is usually represented as “mA-h”. It is actually equal to the total charges available for use:

Battery Capacity = Current x Time = Charge

\[ C = \int I_{ave} \, dT \]

\[ I_{ave} \]

is the average current consumption. In the wake-sleep scenario, average current is the weighted sum between the active current and the sleep current:

\[ I_{ave} = I_{floor} + \frac{1}{T} \int_{T_1}^{T} I_{RX1} \, dt + \frac{1}{T} \int_{T_2}^{T} I_{RX2} \, dt + \ldots \]

In the equation above, \( T_1 \) and \( T_2 \) represents the time for different operation modes during wireless link, and \( T \) is the average intervals for one complete link cycle. \( I_{floor} \) represents the “floor” current when the chip is idle. To make an example, suppose a wireless system has the following characteristics:

- Floor = 1uA (sleep)
- IRX1 = 10mA, lasting for 10ms (receiving)
- IRX2 = 3mA, lasting for 100m (idle)
- \( T = 10 \) sec

The average current is equal to:

\[ 1uA + 0.1\% \times 10mA + 1\% \times 3mA = 41uA \]

As shown above, a floor current of 1uA or 5uA will only make minor difference. For single 620mA-h coin cell (CR2450) with 5-year operation, the required average current is to be below 10uA. With this number, 1uA or 0.1uA floor current may be less a concern and the dynamic behavior of active current loads is more critical.

For large networks, data throughput is more of how many “valid” data is sent: in Zigbee, CSMA/CA is used to resolve the TX conflict among wireless nodes, which requires the MCU to constantly wake up before delivery thus increasing power consumption. This situation gets exponentially worse when network size increases. This behavior can be quantified as \textit{One-Shot-Success-Rate (OSSR)}, defining the delivery success probability when only one transmission trial is allowed. For example, if 5 out of 10 TX-RX trials is failed, OSSR=50%. Let us assume the system-under-test has a floor current of 1uA during sleep. With OSSR=90% and an active average current of 9uA, it can achieve the targeted 5-year battery life (<10uA). Yet the same chipset will alternatively consume 31uA if OSSR falls to 33.3% (two attempts are tried before each packet can pass through due to collision). This corresponds to only 32.3% of previous battery life. It is obvious that protocol choice is far more important than picking a low-leakage wireless IC.

\textbf{ESL “turn-key” offers are more efficient for retailers and their partners}

Undoubtedly \textit{cloud computing} already has posed immense impact at the retail space, such as use of RFID in inventory control and logistics management. Given the complexity of the existing ESL technology architectures, IR or low-frequency-RF alike, from installation to management, it is not surprising that a “close” system is needed to ensure the system reliability. On the contrary, with the new
Interactive RF technology, M2C ESL system behaves similar to your home Wi-Fi router and, certainly, you do not have to be a rocket scientist to learn how to install it. This means that system integrators can easily integrate the ESL turn-key into their total solutions without the system overheads inherited in other ESL vendor system suites.

![M2C "turnkey" ESL system with TCP/IP](image)

**Figure 3: M2C "turnkey" ESL system with TCP/IP**

M2C interactive ESL turnkey system architecture with TCP/IP connectivity

Inspired from the most proven cellular technologies, M2C’s interactive RF ESL solution is delivered in the turnkey format with following features:

- to be integrated with any backend middleware through TCP/IP (IPv4)
- above-5–year tag battery lifetime, independent of network size, using coin-cell batteries
- Interactive wireless technology ensures the tag info to be fully accessed, i.e. battery capacity, error correction, etc.
- Decent network size: one Access Point (AP) can have access to up to 16,000 tags
- Scalable network size with Routers to fit different floor areas
- Flexible router installation without compromising the shelf arrangement due to the ceiling fixtures
- Non-2.4GHz RF co-exists with the Wi-Fi/Bluetooth, with better stability
- Minimal alteration to the in-store decoration without tearing off the ceiling to install the bulky roof antenna.
- Simple architecture minimizes the system maintenance efforts, thanks to our innovative interactive technology.
- High-speed info updates with 10,000 full graphic 2” labels or 100,000 segment labels within one hour.
- Fully supporting the segment and full-matrix e-paper tags

As stated, system integrators in the retail ecosystem can easily bundle the ESL solution with POS, goods movement, warehouse management, inventory control, shelf monitor, and so on, to offer better integrated packages for future retailers. With their own “private” clouds, retailers can easily take the full advantage of the ESL by deploying new marketing strategies. There is no need to buy the expensive ESL software package anymore since these partners may already have the state-of-art solutions in place. The only thing needed is the user interface (UI) for device management and status monitor, and then let the imagination works. Local hypermarket reports 10% of revenue growth even with the current ESL technology, so the new RF turn-key ESL can certainly further reduce the entry barrier so that the benefit can go further to small-to-mid-size retailers like street-corner convenient stores and supermarkets where the
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full-blown ESL solution was way too expensive.

**Summary**

An interactive RF technology is introduced for advanced ESL application. The turnkey delivery facilitates access for service providers and retailers to the ESL solution for maximal integration. Very-low-power RF devices using ultra-high frequency can achieve the genuine interactivity without compromising the battery life, thanks to the patented communication protocol from M²Communcation, Inc. Use of non-2.4GHz spectrum prevents the band coexistence issues with WiFi and 3G signals. Fast update speed is made possible due to use of a high-efficiency MCU and system-on-chip implementation. Other features like image compression and hardware-powered network management further optimize ESL system performance.

**About the Author**

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**About the Company**

M²Communcation, Inc. (M2C) is focusing on the Internet-of-things (IoT) communication system and IC solution. Founded in 2012, M2C delivers the turnkey solution for ultra-low-power, large-network, and wireless applications such as ESL, Smart-power, and so on.

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