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Virtual LEDs for Real-time Monitoring and Debugging in Electronic Hardware

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ABSTRACT

Light-emitting diodes (LEDs) are ubiquitous in electronic hardware, where they serve to indicate device state and/or provide debug information, e.g., during product development. If indicator LEDs are retained in production hardware, equipment owners incur substantial capital and operating costs. This disclosure describes the virtual LED (vLED), a technique that leverages connectivity through an on-board controller such as a baseboard management controller (BMC) to transmit real-time information equivalent to the state of the physical indicator-LED to a log file communicated through a browser or other tool. The vLED provides the equivalent functionalities as a physical LED while costing nearly nothing and enabling the remote access of equipment, the capture of rare events, the analysis of error logs by models, the adding of additional indication-features after general availability (GA) of the equipment, etc.

KEYWORDS

- Light-emitting diode (LED)
- Indicator LED
- Debug LED
- Baseboard management controller (BMC)
- Virtual LED (vLED)
- Data center
- Hardware status

BACKGROUND

Light-emitting diodes (LEDs) are ubiquitous in electronic hardware such as printed circuit boards, where they provide critical debug information during the new product introduction (NPI) phase of product development, e.g., during the bring-up, validation, manufacturing, and test processes. It is normal practice to retain these indicator LEDs in the design even after the hardware has transitioned to full-scale production. In doing so, equipment owners incur substantial capital and operating costs. For example, a single LED might cost only a cent and might consume only modest amounts of energy. However, in a setting such as a data center that has a large amount of electronic hardware, with a correspondingly large number (e.g., hundreds of thousands to millions) of LEDs, sizable capital and operating costs may be incurred on account of such LEDs.

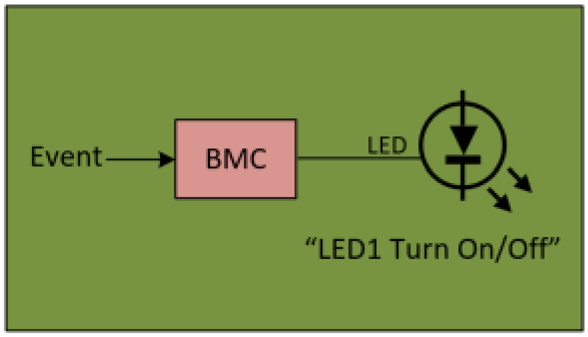

Fig. 1: Operation of a traditional physical indicator LED

Fig. 1 illustrates the operation of a traditional, physical, indicator LED. An event that takes place within the electronic equipment causes the baseboard management controller (BMC) to turn a physical LED on or off. Parameters such as the color of the light emitted by the LED and/or the frequency of its flashing, if any, can be further indications of the state or the health of the electronic equipment.

Although the physical LED is a reliable and widely used visual and real-time indicator of the health of a piece of equipment, it suffers from various drawbacks.

- *Lack of remote access*: A developer or hardware engineer has to be in close proximity to the LED to view it to interpret the state of the equipment.
- *Possible difficulty of viewing*: In equipment densely populated with PCBs, it is possible that an LED is hidden from view, thereby eliminating its utility. An LED in a given piece of

equipment is useful only under substantial location (viewability) restrictions, which in turn place design constraints on the PCB.

- *Inability to add new features, e.g., after mass production*: The physical LEDs on a board being few in number, it is infeasible for new software features added after mass production or general availability (GA) to be indicated upon by a physical LED. Further, since the number of LEDs is fixed per the initial requirements of the design, additional features that may be identified post general availability cannot be easily implemented without a PCB redesign.
- *No easy way to determine the meaning of an LED color or blink rate*: The status or health signaled by an LED varies across equipment: a green-LED blinking at 1 Hertz on a particular PCB might mean that that PCB is performing well, whereas a green-LED blinking at a similar rate on an adjacent PCB might mean that that adjacent PCB needs attention. There is no immediate way for a technician who encounters a variety of machines, each of which may have their own LED mappings and meanings, to ascertain the meaning of LED signaling.
- *Unintuitive location mapping*: Due to the aforementioned location constraints, an LED may be placed on a PCB some distance away from the hardware unit it indicates upon. For example, an LED might indicate the state of the CPU, but due to viewability requirements, it might be placed far away from the CPU, which can cause difficulty in interpreting the condition indicated by the LED (state of the CPU).
- *No easy way to integrate with machine learning*: Given a vector of states of a PCB, a machine learning model can be trained to infer the cause of failure. Because the physical LED status is not logged, and because the LED indicates an event of interest only ephemerally (once the LED flashes, the fact that the event occurred is lost), it is infeasible to integrate physical LEDs with ML models used for debugging. Rare events, or events that

take place when a technician or designer is not looking at the LED, remain uncaptured in error logs and are not amenable to machine learning driven analysis.

- *Opex and capex*: As mentioned before, viewable placement of LEDs on a circuit board requires conscious design effort and therefore, requires additional investment at design time. The incorporation of physical LEDs onto boards is a capital expenditure. Their continued energy consumption is an operating expenditure.
- *Limited LED colors and blink rates*: Physical LEDs have a limited range of colors and blink rates, which limits the number of conditions they can indicate.

DESCRIPTION

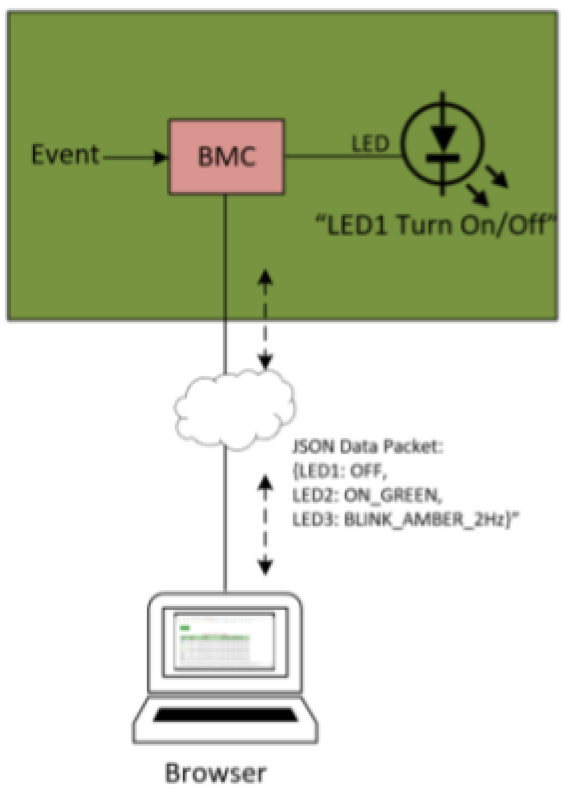

Fig. 2: Virtual LEDs for remote real-time monitoring and debugging

This disclosure describes the virtual LED (vLED), a technique that leverages the existing network interface of the baseboard management controller (BMC) to transmit real-time information equivalent to the state of the physical LED to a log that is viewable from a browser or an external reporting system. The vLED retains the functionalities of the physical LED while addressing its drawbacks and costing nearly nothing.

As illustrated in Fig. 2, as with a physical LED, an event within the electronic equipment triggers the BMC; however, rather than change the state of a physical LED (which may be optionally retained, or eliminated entirely), the BMC (or, equivalently, the CPLD, complex programmable logic device, or other controller/microcontroller) sends to its network interface state change information. The information is transferred over ethernet, serial connection, WiFi, or other suitable interface to a log, which can be accessed by a human (e.g., a technician or an engineer) or by a program (e.g., a script or a machine learning model).

The vLED can transmit information using a lightweight protocol, for example, encoded as a JavaScript Object Notation (JSON) object. Websockets or another suitable mechanism can be used as a transport mechanism for the messages being passed. Some fields in the transmitted information can be, for example, ON/OFF state; color; blink rate; etc. As opposed to a physical LED, which is driven continuously by the BMC, a vLED transmission occurs advantageously upon *change* of state, rather than continuously, as would be encountered with a physical LED. The communication and energy overhead of the vLED is thereby an insubstantial fraction of the total energy consumed and volume of communication handled by the BMC.

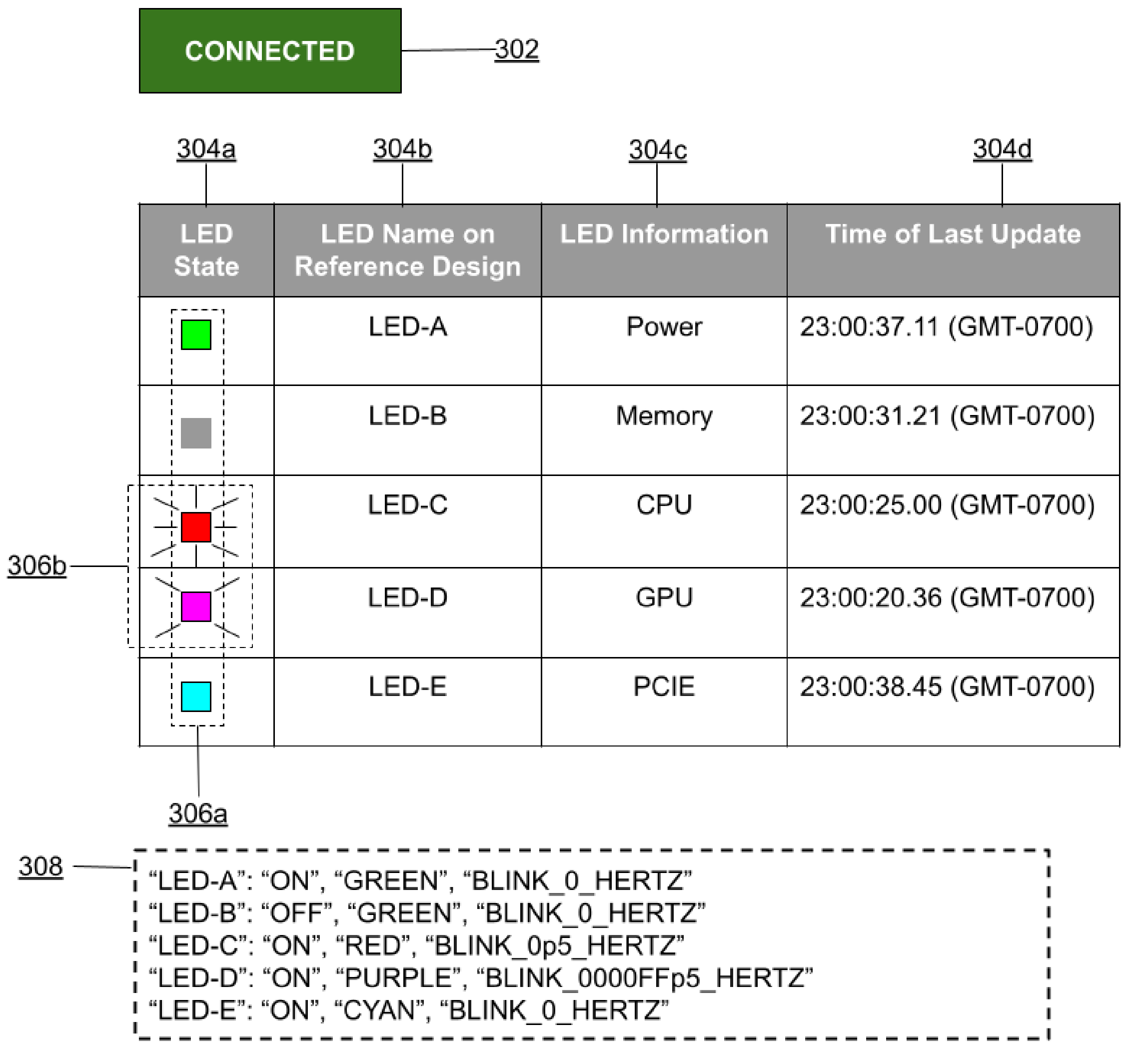

Fig. 3: An example user interface for vLEDs

Fig. 3 illustrates an example user interface for virtual LEDs, seen, e.g., from a browser or other monitoring module. A button (302) indicates the status of the connection of the vLED client (e.g., browser or other tool) to the vLEDs on the PCB. LEDs are columnarly listed by their state (304a); their name on a reference design (304b); additional information pertaining to them, e.g., the module (power supply, memory, CPU, etc.) that they indicate upon (304c); their time of last state update (304d); etc. The state of an LED can be on, off, one of several possible colors (306a), blinking at one or several possible rates (306b), etc.

As opposed to a physical LED, the number of colors and blink-rates available via a vLED is very large, limited only by the specifications of the display. In addition to real-time display, the LED status is also logged, e.g., in a text file, an example of which is illustrated (308). As explained before, the log file can be inspected and processed by humans, automated scripts, machine-learning models, etc. The monitoring module, e.g., browser, or log-processing module such as an ML module, can access the data generated by the vLED over the cloud.

Advantages of vLEDs

As described herein, a vLED offers the same real-time, visual state-indicator functionality of a physical indicator LED. Some advantages of vLEDs include:

- *Enabling remote access*: A hardware technician does not have to walk the length of the data center or other facility and back just to check the debug LEDs of a piece of equipment. They can perform the same job by bringing up the information on their browser or other tool. This is also advantageous if there are restrictions on access to the data center or other facility that can limit the ability of technicians to access the physical machine, or if the technician is working from home.
- *Reducing or eliminating location restrictions on the PCB*: When placing physical LEDs on a PCB, care must be taken to ensure that their locations are visible to the operator and not hidden by cables or chassis covers. There is no such restriction with vLEDs, enabling more flexibility in PCB designs.
- *Enabling post-GA addition of new LEDs*: Physical LEDs that are included as part of a design are retained for the life of the platform with no chance of increasing the LED count or providing additional features. There is no such restriction with vLEDs.

- *LED codes for multiple platforms*: Every platform is different and there is no uniformity in how physical LEDs are placed or assigned meaning. The technician in the data center currently has to remember the meaning of each LED for each platform, with meanings differing across platforms. With vLEDs, the platform is auto detected and the correct LED mapping table is loaded. The technician is now free from having to remember LED codes for each platform. For additional clarity, an image of the platform PCB assembly can be presented to the technician with the actual LED locations already marked.
- *Ready integration with machine learning models*: The diagnostic information provided by the flash of a physical LED is lost once it occurs. With vLEDs, the diagnostic information is time-stamped, recorded, and can be used as additional input to the human or machine-learning model driving diagnosis and debugging.
- *Reduced Opex and Capex*: Post-NPI equipment used in production that switch to vLEDs can save potentially millions of dollars in opex and capex (depending on machine and LED counts, time in service, etc.).

This disclosure describes techniques that virtualize the functions of a physical LED into a virtual LED, thereby saving costs and enabling the remote access of equipment, the capture of rare events, the analysis of error logs by ML models, the provision of additional indication-features after general availability (GA) of the equipment, etc. Servers, storage, networking equipment, and almost any hardware that currently uses physical LEDs can benefit by moving to vLEDs, provided that a BMC, microcontroller unit (MCU), or similar controller is available that can transfer (e.g., via data packets) state change information to a browser or other receiving software. This has very little impact on network utilization since only state change information is sent over the network and the work (e.g., of interpreting the received data and showing a user interface) is performed by the receiving entity.

CONCLUSION

This disclosure describes the virtual LED (vLED), a technique that leverages connectivity through an on-board controller such as a baseboard management controller (BMC) to transmit real-time information equivalent to the state of the physical indicator-LED to a log file communicated through a browser or other tool. The vLED provides the equivalent functionalities as a physical LED while costing nearly nothing and enabling the remote access of equipment, the capture of rare events, the analysis of error logs by models, the adding of additional indication-features after general availability (GA) of the equipment, etc.