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Thermal Mitigation in Mobile Devices

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THERMAL MITIGATION IN MOBILE DEVICES

Abstract

In order to prevent damage and component failure from excess heat in a portable electronic device, thermal mitigation measures often are implemented by a thermal control module of the device. Temperature sensors, such as thermistors, provided with individual components of the device provide temperature information to a processor, which also receives information about the use of the device and its environment. Based on the temperature, usage, and environmental information, the processor determines whether thermal mitigation measures should be implemented to lower the temperature of one or more components to below a threshold and, if so, which mitigation measures to implement in order to do so with minimal impact on the experience of the user of the device.

Background

Portable electronic devices, such as smartphones, tablet computers, multimedia devices, and other mobile processor-based devices, utilize components that may perform poorly, or even become dangerous, when exposed to excessive heat or when internal components generate excessive heat. For example, high temperatures within a device can affect the structural integrity of components and their physical connections, resulting in diminished performance or failure of components altogether. The performance of processors and other circuit components can decline with repeated or continuous exposure to excessive heat.

Such portable electronic devices typically include thermal management modules that monitor the temperatures within the system and execute thermal mitigation procedures upon detecting high temperatures in order to mitigate the undesirable results which can occur due to excessive heat within the system. The thermal mitigation measures implemented by a portable electronic device can include, for example, processor throttling, clock gating, dynamic voltage and frequency scaling (DVFS), and activity migration (that is, shifting workloads from components with higher temperatures to those with lower temperatures). These thermal mitigation measures can result in temporarily reduced processing speeds and/or reduced functionality of the device, which can be detrimental to the user experience. Further, thermal mitigation measures are typically implemented automatically and are initiated on, for example, a predetermined schedule or as a result of temperature readings exceeding a threshold, regardless of the efficacy of the measures or their impact on the performance of the device and, consequently, on the user experience.

Description

As cellular networks evolve to meet the demand for increased data at higher speeds, the complexity of the devices that communicate over cellular networks continues to increase as faster processors and more specialized components are incorporated into the devices. Because these components produce heat during operation, dynamic and targeted thermal mitigation measures that have minimal impact on device performance and user experience are needed to prevent damage and component failure within devices.

While thermal mitigation measures are implemented in most portable electronic devices, the disclosed systems and methods contemplated herein are described, for purposes of example, in the context of a mobile cellular phone. A block diagram illustrating components of an example cellular phone is shown in FIG. 1 below. The device includes a System on a Chip (SoC), a modem, memory (e.g., Random Access Memory (RAM)), cache storage, various integrated circuits, and a user interface (e.g., a touch-sensitive screen). In a mobile phone, the SoC is typically referred to as the “application processor” as it is designed to support applications running in a mobile operating system environment and can include graphics processing and memory management components. In some implementations, the SoC also includes other specialized processors, such as a wireless communications processor. However, in some devices, the wireless processor is not integrated into the SoC but provided as an independent processor (as illustrated in FIGs. 2 and 3).

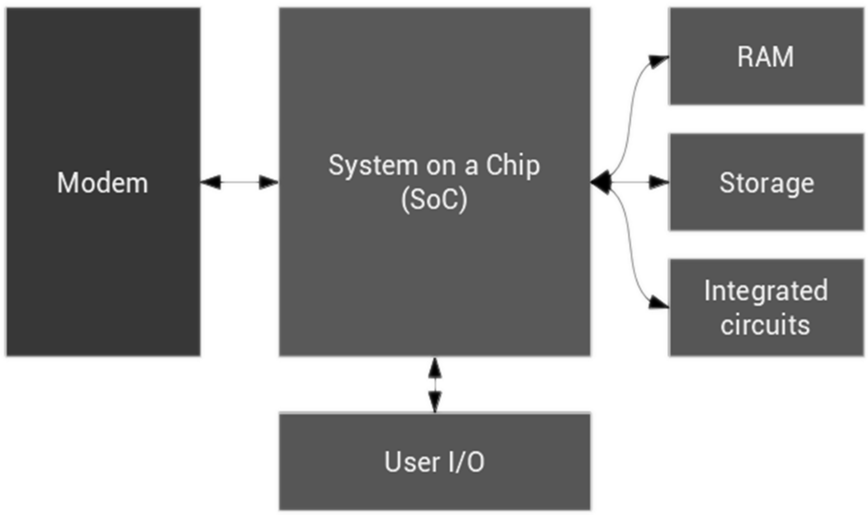

FIG. 1

Thermal management of the device is controlled, in part, by at least one thermal management module (implemented as software, programmable logic, or hardwired circuitry) that receives temperature data from components of the device, which is used to determine if mitigation actions should be initiated and, if so, which components will implement the actions. Thermal control modules are provided at the application processor and the wireless processor. The thermal control module of the wireless processor includes modules configured to implement specific thermal mitigation actions. For example, the thermal control module of the wireless processor can include modules to reduce the number of receiving antennas, change the radio access technology (RAT) configuration, reduce downlink bandwidth, reduce uplink throughput, notify the network to reduce downlink payload size, and/or a central processing unit (CPU)/memory bus clock rate module.

In communication with the thermal control module(s) are temperature sensors, such as thermistors, provided with individual components of the device, such as the modem or millimeter wave (mmWave) modules. The temperature-varying nature of a thermistor's resistance results in a temperature-varying output voltage, which can be converted to an estimated temperature based on the thermistor's voltage-to-temperature relationship. The processor can use this temperature reading, in conjunction with information regarding the use of the device by a user and the environment in which the device is being used, to determine where and how mitigation actions should be employed in order to reduce the temperature of a given component to below a threshold level.

FIG. 2 below is a block diagram illustrating a thermal management method implemented by the wireless processor (referred to as the "wireless technology processor" in FIG. 2) in which the wireless processor receives temperature information and device usage information in order to determine thermal mitigation actions. The wireless processor receives temperature information via interrupt request (IRQ) from thermistors provided at the mmWave modules and the modem, such as the radio frequency (RF) front end, the power amplifier (PA), and/or external low-noise amplifier (eLNA). Temperature information from the application processor is also reported to the wireless processor via inter-process communication (IPC) over an interface between the application processor and wireless processor, which allows for the real-time exchange of information with minimal power consumption.

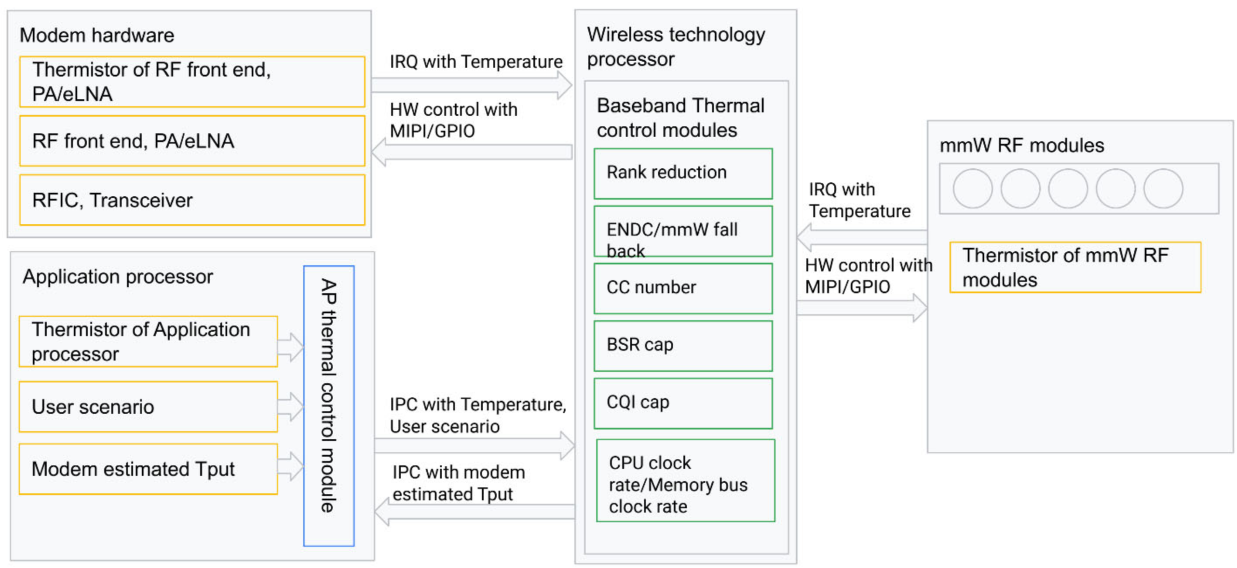

FIG. 2

The wireless processor converts the temperature information from each of the thermistors into a temperature reading for each of the associated components and compares it to a predefined threshold. If the temperature of a component exceeds the associated threshold, the wireless processor triggers the application processor to provide information regarding how the device is currently being used. This usage information from the application processor can, for example, include applications currently running on the device, the types of networks the device is connected to, and whether the device is utilizing voice and data capabilities or just voice capabilities. The wireless processor can then determine whether thermal mitigation actions are needed at a specific component and, based in part on the usage information, which mitigation actions should be initiated in order to reduce the temperature of the component to below the threshold with minimal impact to device performance.

For example, if the wireless processor determines that a mmWave RF module has exceeded its threshold temperature and the usage information does not indicate that E-UTRAN New Radio–Dual Connectivity (ENDC) is required by any applications currently being executed by the device, the wireless processor can signal the ENDC/mmW fallback module of the thermal control modules to disable ENDC at the mmW RF module, thus reducing the power usage of the mmWave RF module and lowering the temperature. In another example, the wireless processor receives temperature information from a thermistor associated with the RF front end of the modem and, after converting the temperature information to a temperature reading and comparing it to a threshold associated with the RF front end, determines that the temperature of the RF front end is operating at a temperature in excess of the threshold for the RF front end and that thermal mitigation actions are needed to bring the temperature down. The wireless processor then requests usage information from the application processor and, if the usage information indicates that the signal strength of the network to which the device is connected is strong, one of the thermal control modules of the wireless processor can implement a power cap on the RF front end, thus reducing the heat generated by the components of the RF front end.

In another implementation, the thermistors associated with components of the system can provide temperature information to the application processor, as illustrated in the block diagram of FIG. 3. The application processor receives the temperature information from the thermistors, converts it to temperature readings, and compares the temperature readings to thresholds associated with each of the components for which temperature information was received. When a temperature reading for a given component exceeds the corresponding threshold, the application processor reports usage information to the wireless processor, along with the indication that thermal mitigation is needed to bring the temperature of the component to within acceptable levels. In response to receiving this information, the wireless processor determines which mitigation action(s) to take and signals the thermal control module(s) to implement the appropriate actions.

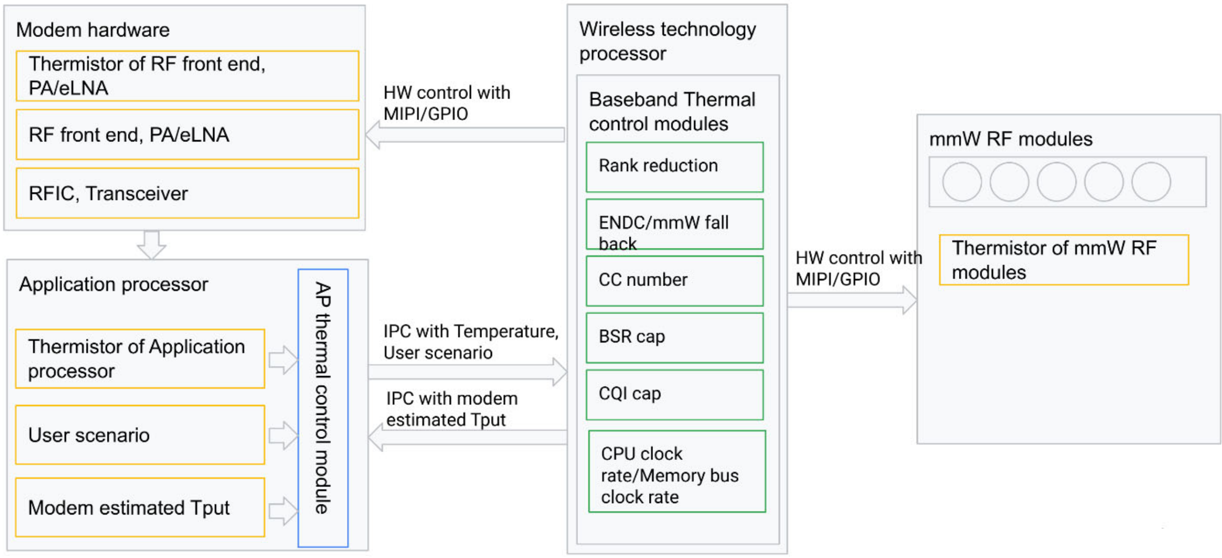

FIG. 3

Because the thermistors are continuously providing temperature information to the application processor and/or the wireless processor, the implementation of mitigation actions can take place as needed, rather than on a set schedule. Further, because the determination of which mitigation actions to implement is based, in part, on usage information, the mitigation actions can be dynamically adjusted to minimize the impact on the user experience by taking into account performance and/or capability requirements of the device and applications running on the device at a given point in time.

References

Systems and methods for thermal mitigation with multiple processors, U.S. Patent Pub. No. 20130332720, filed Feb. 28, 2013, the entirety of which is hereby incorporated by reference.

Circuits and methods providing temperature mitigation for computing devices using in-package sensor, U.S. Patent Pub. No. 20170083063, filed Sept. 21, 2015, the entirety of which is hereby incorporated by reference.

Thermal mitigation in devices with multiple processing units, U.S. Patent Pub. No. 20160179180, filed Dec. 22, 2014, the entirety of which is hereby incorporated by reference.