April 2021

Thermal Mitigation at User Equipment Based on Ambient Temperature

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THERMAL MITIGATION AT USER EQUIPMENT BASED ON AMBIENT TEMPERATURE

Abstract

User equipment (UE) or other user devices employ thermal mitigation schemes that are responsive to the ambient temperature of the device. Such schemes can employ different levels or modes of thermal mitigation techniques based on ambient temperature, the thresholds that trigger the switch between levels or modes may be scaled based on ambient temperature, or a combination thereof.

Background

Smartphones, smartwatches, tablet computers, and other user equipment (UE) typically employ a static thermal mitigation scheme in which processes or features employed at the UE are taken offline or brought online, or are otherwise modified, based on one or more measured temperatures of the UE relative to corresponding thresholds. However, such UE often are subject to varying ambient temperature conditions based on geographical location, time of year, time of day, location inside or outside, and the like, and thus static temperature thresholds often do not provide the most effective triggers for thermal mitigation in UEs.

Description

FIG. 1 below illustrates a UE employing a thermal mitigation subsystem based on ambient temperature considerations. The UE employs one or more device sensors to obtain temperature readings at one or more locations of the UE, including on the circuit boards, at individual components, near the case, and the like. Similarly, the UE employs one or more ambient sensors to obtain ambient temperature readings; that is, the temperature of the ambient environment surrounding the UE. Alternatively, the UE obtains ambient temperature readings by supplying its location to a weather server or other source of location-based current ambient temperatures. These temperature readings are fed to a thermal management module, which filters or otherwise pre-processes the ambient temperature readings and device temperature readings. The resulting processed temperature readings are then used to selectively implement thermal mitigation techniques to prevent overheating of the components of the UE or to prevent the UE from reaching a surface temperature that is uncomfortable to the user. These thermal mitigation techniques can include activating or deactivating processes, activating or deactivating particular process features, modifying the operation of a process (e.g., via a clock frequency change, a voltage supply level, or other operational setting), and the like.

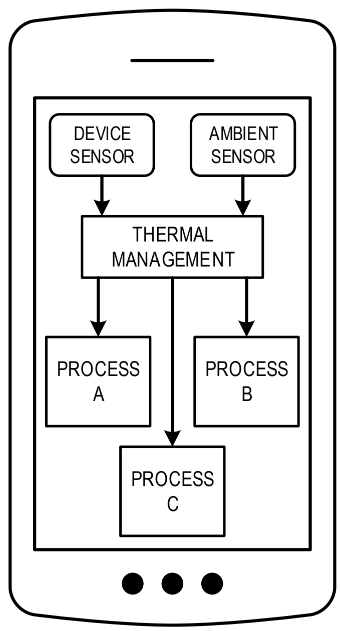

FIGURE 1

Conventional thermal management schemes compare the device temperature readings to fixed temperature thresholds in order to determine whether to enact a corresponding thermal mitigation technique. However, this fails to account for the impact of ambient temperature. For one, as the rate of thermal energy transfer from the UE is proportional to the difference between the UE temperature and the ambient temperature (referred to herein as "ΔT"), the UE is capable of shedding thermal energy at a greater rate for a lower ambient temperature than at a higher ambient temperature. Thus it may not be as necessary to trigger a thermal mitigation technique at a fixed UE temperature threshold while still providing for user comfort. Further, a user's perception of the temperature of the UE is often dependent on the ambient temperature, such that the UE having a surface temperature of, for example, 45 degrees Celsius (ºC) may not feel as warm to a user when the ambient temperature is 40 ºC compared to when the ambient temperature is 10 ºC. As such, the UE can implement one or more ambient-aware thermal management schemes that efficiently leverage the impact of ambient temperature, or the ΔT between UE temperature and ambient temperature, for heat management at the UE as described below.

Ambient Temperature-Based Thermal Mitigation

One ambient-aware thermal management scheme employs a mitigation strategy that uses one of two mitigation modes depending on the ambient temperature: (1) a relaxed thermal mitigation mode employed when the ambient temperature is below a mode switch threshold; and (2) an aggressive thermal mitigation mode employed when the ambient temperature is at or above the mode switch threshold. This mode switch threshold may be specified by the manufacturer of the UE, by a provider of the UE, by a user, and the like. For ambient temperatures below the mode switch threshold, the modem or other cellular radio access technology (RAT)-related components of the UE have more "runway" to cool down before the UE is required to switch these components to supporting only limited cellular service or even emergency shutdown. Accordingly, the relaxed thermal mitigation mode at these lower ambient temperatures provides for the use of less-aggressive thermal mitigation techniques that have less impact on the performance of the cellular RAT components. Further, the relaxed thermal mitigation mode may employ different levels, with each level triggered when the ambient temperature exceeds a corresponding level threshold, which again may be specified by any of a variety of interested parties.

Conversely, for ambient temperatures at or above the mode switch threshold, cellular RAT components of the UE have less "runway" to cool down before the UE is required to switch these components to supporting only limited cellular service or even emergency shutdown. Accordingly, the aggressive thermal mitigation mode at these higher ambient temperatures provides for the use of more-aggressive thermal mitigation techniques that have a greater impact on the performance of the cellular RAT components. As with the relaxed thermal mitigation mode, the aggressive thermal mitigation mode also can employ different levels, with each level triggered when the ambient temperature exceeds a corresponding level threshold, which again may be specified by any of a variety of interested parties.

The charts below illustrate example thermal mitigation techniques, or "actions," that can be employed at different levels of the different modes. For reference, "LTE" refers to a Third Generation Partnership Project (3GPP) Fourth Generation (4G) Long Term Evolution (LTE) RAT, "NSA" and "SA" refer to the Non-Stand Alone and Stand Alone modes, respectively, of the 3GPP Fifth Generation (5G) New Radio (NR) RAT, "FR1" and "FR2" refer to Frequency Range 1 and Frequency Range 2, respectively, of 5G NR, "DL" and "UL" refer to the downlink and uplink, respectively, between the UE and the corresponding base station, "Scell" refers to a serving cell, and "BWP" refers to bandwidth parts. Further, as illustrated below in the relaxed mitigation mode, while in the critical level, the UE can employ a sequence of timers, T1, T2, and T3, the expiration of each (referred to as "T1 Exp," "T2 Exp," and "T3 Exp," respectively) triggers an increasingly more aggressive thermal mitigation technique. When entering the critical level, timer T1 is initiated and upon its expiration, a corresponding thermal mitigation technique is employed. Concurrently, timer T2 is initiated and upon its expiration, a corresponding more-aggressive thermal mitigation technique is employed, and so forth.

Relaxed Mitigation	**Actions**			
Thermal Mitigation Level	**LTE**	**NSA FR1**	**SA FR1**	**NSA FR2**
0 / Moderate	No action	No action	No action	No action
1 / Severe	Periodic drop in UL data rate	* Drop to lowest BWP configuration * Drop to lowest modulation scheme * Drop no. of layers (4Rx to 2Rx) * Drop to lowest UL rate * Drop support for mini-slots / slot aggregation UL: * Drop to lowest UL rate	N/A	DL & UL * Drop to minimum no. of antenna elements * Drop no. of layers (4Rx to 2Rx) * Use other techniques from modem to reduce MIPS DL: * Drop all Scells UL: * Drop all Scells * Drop to lowest UL rate
2 / Critical	**Start T1:** **T1 Exp:** Drop no. of layers **Start T2** **T2 Exp:** Drop to lowest modulation scheme **Start T3:** **T3 Exp:** 1. Periodic drop in UL data rate 2. Periodic drop of Scells	Disable 5G, Fall back to LTE	N/A	Disable 5G, Fall back to LTE
3 / Emergency	* Disable LTE	NOP	N/A	NOP

Aggressive Mitigation	**Actions**			
Thermal Mitigation Level	**LTE**	**NSA FR1**	**SA FR1**	**NSA FR2**
0 / Moderate	No action	No action	No action	No action
1 / Severe	* Drop to lowest UL rate	* Drop to lowest BWP configuration * Drop to lowest modulation scheme * Drop no. of layers (4Rx to 2Rx) * Drop to lowest UL rate * Drop support for mini-slots / slot aggregation UL: * Drop to lowest UL rate	N/A	DL & UL * Drop to minimum no. of antenna elements * Drop no. of layers (4Rx to 2Rx) * Use other techniques from modem to reduce MIPS DL: * Drop all Scells UL: * Drop all Scells * Drop to lowest UL rate
2 / Critical	* Drop all Scells * Drop no. of layers * Drop to lowest modulation scheme * Drop to lowest UL rate	Disable 5G, Fall back to LTE	N/A	Disable 5G, Fall back to LTE
3 / Emergency	* Disable LTE	NOP	N/A	NOP

Adaptive Trigger for Thermal Mitigation Based on User Perception of Temperature

As explained above, thermal mitigation schemes typically employ temperature thresholds to control the selection of a particular mode or level of thermal mitigation to be employed by the UE. Conventionally, these thresholds are fixed. However, in the scheme described below, the ambient temperature plays a factor in scaling these thresholds in view of the fact that user perception of the temperature of the UE is dependent on the ambient temperature, and more specifically, on the ΔT between UE temperature and ambient temperature. Two example approaches are described below for three temperature thresholds that can represent the mode trigger thresholds between three or more thermal mitigation modes, the level trigger thresholds between three or more levels of a thermal mitigation mode, and the like. It will be appreciated that this same general approach can be employed to update some or all of the multiple thresholds employed in some thermal management schemes, such as the one described above.

For both approaches, the following nomenclature is used:

Td = device (UE) temperature

Ta = ambient temperature (from an ambient temperature sensor or a weather server)

ΔT = Td – Ta, the difference between device (UE) temperature and ambient temperature

TLevel1 = first temperature threshold

TLevel2 = second temperature threshold > TLevel1

TLevel3 = third temperature threshold > TLevel2

S = static scaling factor, specified by a user, UE provider, UE manufacturer, etc.

First Approach:

The temperature threshold TLevel1 is updated using the expression:

TLevel1 = TLevel1 – (ΔT/T)*S

The temperature threshold TLevel2 is updated using the expression:

TLevel2 = TLevel2 + (ΔT/T)*S

The temperature threshold TLevel3 is updated using the expression:

TLevel3 = TLevel3 + (ΔT/T)*S

In this approach, when the ambient temperature Ta is lower, ΔT is greater and thus moves the first temperature threshold to a lower temperature, thus triggering an earlier entry into the lower level of thermal mitigation. However, the second and third temperature thresholds are shifted up to higher temperatures, thus delaying entry into their respective thermal mitigation levels. Conversely, when the ambient temperature Ta is higher, ΔT is lower and thus moves the first temperature threshold to a higher temperature, thus delaying entry into the lower level of thermal mitigation.

Second Approach:

The temperature threshold TLevel1 is updated using the expression:

$$TLevel1 = TLevel1 + (\Delta T/T)*S$$

The temperature threshold TLevel2 is updated using the expression:

$$TLevel2 = TLevel2 + (\Delta T/T)*S$$

The temperature threshold TLevel3 is updated using the expression:

$$TLevel3 = TLevel3 + (\Delta T/T)*S$$

In this approach, a lower ambient temperature moves the first temperature threshold to a higher temperature, therefore triggering a later entry into the lower level of thermal mitigation, whereas a higher ambient temperature moves the first temperature threshold to a lower temperature, thus triggering an earlier entry into the lower level of thermal mitigation. Conversely, the second and third temperature thresholds are shifted up or down depending on whether the device temperature is greater than or less than the ambient temperature.

References

1. U.S. Patent Application Publication No. 2015/0148981 filed on November 24, 2013 and entitled "System and method for multi-correlative learning thermal management of a system on a chip in a portable computing device," the entirety of which is incorporated herein.
2. U.S. Patent Application Publication No. 2020/0329431 filed on April 12, 2019 and entitled "Method and apparatus for thermal management in wireless communication," the entirety of which is incorporated herein.
3. U.S. Patent Application Publication No. 2015/0057830 filed on September 11, 2013 and entitled "Method and apparatus for adjusting portable electronic device operation based on ambient temperature," the entirety of which is incorporated herein.
4. U.S. Patent Application Publication No. 2019/0379427 filed on April 22, 2019 and entitled "Antenna element feed path component management for 5g-nr millimeter wave," the entirety of which is incorporated herein.
5. U.S. Patent Application Publication No. 2020/0351638 filed on November 17, 2017 and entitled "Temporary Handling of Wireless Communication Device Capabilities," the entirety of which is incorporated herein.
6. U.S. Patent Application Publication No. 2014/0240031 filed on February 27, 2013 and entitled "System and method for tuning a thermal strategy in a portable computing device based on location," the entirety of which is incorporated herein.
7. U.S. Patent Application Publication No. 2014/03719 filed on June 16, 2013 and entitled "System and method for estimating ambient temperature of a portable computing device using a voice coil," the entirety of which is incorporated herein.

8. U.S. Patent Application Publication No. 2015/0029032 filed on May 31, 2012 and entitled "Ambient and processor temperature difference comparison," the entirety of which is incorporated herein.