ISSN: 2583-9888
DOI: doi.org/10.51219/JAIMLD/priyank-anurag/121

URF PUBLISHERS
connect with research world

Journal of Artificial Intelligence, Machine Learning and Data Science

https://urfpublishers.com/journal/artificial-intelligence

Vol: 1 & Iss: 1 *Review Article*

In-Depth Review of Power Negotiation Stack and Power Policies in USB PD-based System

Priyank Rathod* and Anurag

Intel Corporation, Folsom, CA, USA

Citation: Rathod P, Anurag. In-Depth Review of Power Negotiation Stack and Power Policies in USB PD-based System. *J Artif Intell Mach Learn & Data Sci 2022*, 1(1), 434-437. DOI: doi.org/10.51219/JAIMLD/priyank-anurag/121

Received: 01 January, 2022; **Accepted:** 18 January, 2022; **Published:** 20 January, 2022

***Corresponding author:** Priyank Jayantilal Rathod, Intel Corporation ,Folsom,CA, USA, E-mail: rathodpriyank@gmail.com

ABSTRACT

USB Power Delivery (USB PD) is a charging technology that has revolutionized the way devices are powered and charged. It plays a crucial role in the current landscape of electronic devices for several reasons like Increased Power Levels, Universal Compatibility, Intelligent Power Management, Enhanced safety features. This enhances the charging experience by providing faster, more efficient, and safer power delivery across a wide range of devices. One key challenge in achieving this is the power negotiation stack, which enables devices to negotiate the amount of power they can draw from the source. This literature review aims to provide an overview of the current state of knowledge on power negotiation stacks in USB power delivery.

1. Introduction

USB power delivery allows devices to receive power over the same cable used for data transfer. With the increasing demand for more powerful devices, the USB Implementers Forum (USB-IF) introduced the Power Delivery (PD) specification in 2012, which allows for higher currents and voltages. The power negotiation stack is a critical component of USB PD, enabling devices to negotiate the amount of power they can draw from the source. This involves two main components: the Source and the Sink.

Source: The device that provides power, typically a host or a hub.
Sink: The device that receives power, typically a peripheral or a battery charging system.
Various policies and protocols are in place to make sure the power negotiation takes place effectively and the USB PD communication stack facilitates the compliance of them.

2. USB Power Delivery Necessity

Some challenges faced when charging USB devices such as power banks, cell phones, and tablets through USB port include devices drawing more current than the standard USB port specification, Inaccurate specifications of power banks, Potential risks of system malfunction due to overloading the host computer power system when charging multiple devices through USB ports, etc. Varying power requirements of USB devices calls for the solution of managing power delivery between these devices like the implementation of adaptive power management[1]. These problems highlight the importance of establishing and adhering to robust USB power delivery standards to ensure the safety, compatibility, and efficiency and the importance of power negotiation by USB PD.

Advancements in USB technology have enabled higher power outputs through USB Type-C connectors as they support increased power delivery, allowing for charging of devices and powering peripherals efficiently. Research shows that evolution of USB power delivery capabilities is crucial for engineering projects that require reliable power sources for various applications and devices[2].

3. Power Roles within USB PD

In the USB Power Delivery (USB PD) ecosystem, the roles of devices are distinctly categorized into Sources and Sinks based on their power supply and consumption dynamics. A Source is a USB PD port that supplies power, while a Sink is a port that consumes power. Each PD connection between Port Partners comprises one Source Port and one Sink Port. These roles are not static; they can be swapped orthogonally to each other, allowing for flexible power management across devices. Devices supporting both Source and Sink roles are termed Dual-Role Power Ports (DRP), enhancing the versatility of USB Type-C ports. Additionally, when USB Communications Capability is supported, a port can act as a USB Host (in the DFP role) or a USB Device (in the UFP role), further broadening the functional scope of USB PD. This dynamic role assignment and swapping mechanism underpin the operational flexibility and efficiency of the USB PD specification, catering to a wide array of device charging and power management requirements.

3.1. Key Components in USB PD Power Negotiation

- **Policy Engine:** Manages the power negotiation policy, making decisions based on the capabilities and needs of the devices involved.
- **Protocol Layer:** Handles the creation, sending, and receiving of messages between devices.
- **Physical Layer:** Manages the physical transmission of messages, including appending and checking CRCs to ensure message integrity.
- **MessageID and CRC:** Used for ensuring the integrity and uniqueness of each message sent and received during the negotiation process.

4. USB PD Power Negotiation Methodology

The USB Power Delivery (USB PD) communication stack is a sophisticated architecture designed to facilitate the exchange of messages and power negotiation between devices. At its core, the stack comprises several key components: the Device Policy Manager, Policy Engine, Protocol Layer, and Physical Layer, refer to **(Figure 1)**. The Device Policy Manager oversees USB PD resources within a device across multiple ports, implementing the device's Local Policy. The Policy Engine, associated with each USB PD Port, executes the Local Policy for that specific port. The Protocol Layer is pivotal in enabling the exchange of messages between Source and Sink Ports, forming the backbone of communication in the USB PD protocol. Lastly, the Physical Layer handles the transmission and reception of bits on the wire, ensuring the integrity and efficiency of data transmission. This layered architecture not only ensures robust and flexible communication between devices but also supports the dynamic negotiation of power delivery, role swapping, and error handling, making USB PD a cornerstone of modern device charging and power management[3].

4.1. Device policy manager

The Device Policy Manager ensures that each port offers or requests an appropriate set of power capabilities, tailored to the specific requirements of connected devices and the limitations of the hardware.

For Source Ports, the Device Policy Manager determines the maximum power capabilities based on the port's current rating, the type and rating of the inserted cable, and the overall power supply resources available. It also takes into account the power allocated to other ports and any reserved power, ensuring a balanced distribution of power resources across the device. When managing Sink Ports, it evaluates the power capabilities offered by the Source, seeking an optimal match that respects the constraints of the port and cable, while meeting the operational needs of the Sink.

In devices with Dual-Role Power Ports, the Device Policy Manager adeptly manages the transition between Source and Sink roles, facilitating Power Role Swaps to adapt to changing power supply and consumption scenarios. This adaptability is crucial for devices that can alternate between providing and consuming power, enhancing the flexibility and efficiency of power management.

The scalability of the Device Policy Manager's functionality allows it to cater to a wide range of devices, from simple power supplies to complex multiport systems, including those with a mix of USB PD and non-USB PD ports. Its ability to interface with the Policy Engine and, optionally, the System Policy Manager over USB, enables a cohesive and dynamic power management strategy that aligns with the device's local policies and the broader system-wide objectives.

4.2. Policy engine

The Policy Engine is responsible for orchestrating message sequences and responses that facilitate various USB PD operations, including power negotiation and cable plug discovery. It operates based on a set of defined Atomic Message Sequences (AMS), which are critical message sequences that maintain the port in specific ready states, such as PE_SRC_Ready, PE_SNK_Ready, or PE_CBL_Ready. These sequences are essential for the smooth operation of Sources, Sinks, and Cable Plugs, guiding the flow of communication and ensuring that each component is prepared for the next step in the process.

In basic message exchanges, the Policy Engine instructs the Protocol Layer to send messages, initiating a sequence that involves message creation, CRC (Cyclic Redundancy Check) appending and verification, and the eventual acknowledgment of message receipt. This process underscores the Policy Engine's role in ensuring accurate and reliable communication between devices.

During power negotiation, the Policy Engine's responsibilities are further highlighted. It drives the negotiation process through distinct phases, starting with the Source outlining its power capabilities, followed by the Sink evaluating and selecting a power level, and culminating in the Source accepting the request and transitioning to a new power level. The Policy Engine ensures that each step is executed according to the Local Policy, facilitating a seamless negotiation that results in the Sink utilizing the new power level.

4.3. Protocol layer

The Protocol Layer is integral to the USB PD ecosystem, serving as the intermediary that translates policy decisions into actionable communication. It handles both Control and Data Messages, each serving distinct purposes. Control Messages, being short and concise, are used for managing message flow and executing simple commands, while Data Messages carry detailed information necessary for power negotiation, system testing, and vendor-specific communications. This differentiation in message types allows for a flexible and robust communication framework capable of supporting the complex interactions required in power delivery and device communication.

This layer is entrusted with the meticulous task of constructing messages in strict adherence to the USB PD specification, meticulously formatting them with the correct headers, data objects, and Cyclic Redundancy Checks (CRCs) for error verification. Beyond message construction, the Protocol Layer is also responsible for timing within the USB PD communication process, managing timers and timeout values to ensure a smooth and efficient flow of communication and that devices adhere to expected response times. To bolster the reliability of communication, especially under conditions where messages may not be successfully received or acknowledged, it employs retry counters, facilitating message retransmissions as needed. The layer's responsibilities extend to maintaining the integrity of communication through the initiation of reset operations and adept handling of errors, swiftly addressing any communication or protocol discrepancies. Furthermore, it oversees the state behavior of messages, skillfully managing the initiation and termination of message sequences to guarantee that messages are dispatched and received in the correct order and operational state. Through these comprehensive functions, the Protocol Layer ensures the seamless and reliable exchange of information and power negotiation across the USB PD ecosystem

4.4. Physical layer

The PHY Layer is the bedrock of communication in the USB PD specification, facilitating the physical transmission and reception of packets across the USB PD interface. It operates on a single signal wire, utilizing either the VBUS or CC lines, and supports half-duplex communication. This design allows for a streamlined and effective communication channel between devices, which is essential for the dynamic negotiation of power delivery and data exchange that characterizes USB PD interactions.

It is tasked with the critical functions of managing the transmission and reception of packet data, ensuring that messages are accurately encoded for transmission and decoded upon reception. A pivotal aspect of its responsibility includes the calculation and validation of Cyclic Redundancy Check (CRC) for all packets, serving as a robust error-checking mechanism that maintains the integrity of data transmission across the USB PD interface. Employing specialized signaling technologies, such as Binary Frequency Shift Keyed (BFSK) modulation over VBUS and Biphase Mark Coding (BMC) over CC, the PHY Layer minimizes communication errors, facilitating reliable data transfer. Additionally, it implements collision avoidance strategies to navigate the half-duplex nature of communication, ensuring that the single signal wire remains clear for uninterrupted data exchange. Upon successful CRC validation, the PHY Layer forwards packet data to the protocol layer for further processing, while invalid CRCs lead to the flushing of received data, preventing the propagation of erroneous information. Through these integrated functions, the PHY Layer ensures the foundational infrastructure for efficient and error-minimized communication within the USB PD ecosystem, making it indispensable for the negotiation of power delivery and information exchange between devices.

5. USB Power Delivery Power Profiles and Newer Profile Rules

The evolution of USB Power Delivery (USB PD) from its initial specification to the latest revisions has seen a shift from fixed power profiles to more flexible power rules. This transition reflects the growing need for adaptability in power delivery to accommodate a wide range of devices with varying power requirements. Below is a detailed overview of the original power profiles and the newer profile rules that have replaced them.

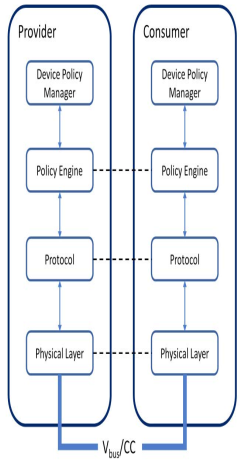

Figure 1: USB PD communication stack.

Original Power Profiles (USB PD Rev. 1.0):

In the first version of USB PD, six fixed power profiles were defined for power sources. These profiles were designed to standardize the power levels that could be delivered to devices, making it easier for devices and power sources to negotiate a compatible power delivery arrangement. The profiles were as follows:

1. Profile 1: 5V @ 2A (10W)
2. Profile 2: 5V @ 2A or 12V @ 1.5A (18W)
3. Profile 3: 5V @ 2A or 12V @ 3A (36W)
4. Profile 4: 5V @ 2A, 12V @ 3A, or 20V @ 3A (60W)
5. Profile 5: 5V @ 2A, 12V @ 5A, or 20V @ 5A (100W)

These profiles allowed devices to request a certain level of electrical power from the power source, with the flexibility to support up to 5A and 20V depending on the supported profile.

Transition to Power Rules (USB PD Rev. 2.0 and Beyond):

With the release of USB PD Rev. 2.0 and subsequent revisions, the fixed power profiles were deprecated in favor of a more flexible system known as "Power Rules." This new system introduced four normative voltage levels at 5V, 9V, 15V, and 20V, allowing power supplies to support any maximum source output power from 0.5W to 100W. The key aspects of the Power Rules include:

- **Flexible Voltage Levels:** Instead of being restricted to fixed profiles, devices and power sources can negotiate power delivery across multiple voltage levels, enhancing compatibility and efficiency.
- **Augmented Power Delivery:** The Power Rules accommodate a broader range of power delivery options, supporting up to 100W, which caters to the needs of more power-intensive devices like laptops and monitors.
- **Granular Power Management:** The introduction of the Programmable Power Supply (PPS) protocol in USB PD Rev. 3.0 further refined power management by allowing for granular control over the output voltage and current, facilitating optimized charging for devices.

- Extended Power Range (EPR) and Adjustable Voltage Supply (AVS) (USB PD Rev. 3.1 and 3.2):
- The latest revisions, USB PD Rev. 3.1 and 3.2, introduced the Extended Power Range (EPR) mode and the Adjustable Voltage Supply (AVS) protocol, respectively. These enhancements allow for even higher voltages and more precise control over power delivery:
- **EPR Mode:** Supports higher voltages of 28V, 36V, and 48V, providing up to 240W of power. This mode requires specially designed cables (EPR cables) that can handle the increased power levels.
- **AVS Protocol:** Allows specifying the voltage from a range of 15V to 48V in 100mV steps under EPR mode, offering unprecedented flexibility in power delivery. With USB PD Rev. 3.2, the AVS protocol was extended to work with the standard power range (SPR), enhancing its versatility.

6. Power Negotiation Benefits

Power negotiation is essentially a communication process between the power source (such as a charger or a laptop) and the power sink (such as a smartphone or a tablet) to determine the optimal power level for charging. This process is vital for several reasons:

1. **Optimal Power Utilization:** Power negotiation ensures that devices receive the precise amount of power they need for charging or operation. This optimizes power usage, preventing undercharging or overcharging, which can extend battery life and improve device performance.
2. **Universal Compatibility:** Through power negotiation, a wide range of devices with different power requirements can use the same USB PD charger. The charger and the device communicate to agree on a power level that suits the device, making USB PD highly versatile and reducing the need for multiple chargers.
3. **Enhanced Safety:** Power negotiation includes mechanisms to manage power delivery safely. It helps in preventing overheating and potential damage by ensuring that devices do not draw more power than they can handle or more than the charger can supply.
4. **Dynamic Power Adjustment:** USB PD's power negotiation allows for dynamic adjustment of power levels based on the device's current needs. For example, a laptop might draw more power when running high-performance tasks and less power when in standby mode. This dynamic adjustment helps in efficient power management.
5. **Bi-Directional Charging:** USB PD supports bi-directional power flow, meaning that power negotiation can determine not only how a device is charged but also how it can charge other devices. For instance, a laptop can charge a smartphone, or a smartphone can charge accessories like wireless earbuds, based on negotiated power levels.
6. **Support for Alternate Modes:** Power negotiation is also crucial when USB PD is used in conjunction with Alternate Modes, such as DisplayPort or Thunderbolt 3. It ensures that while data or video signals are being transmitted, power delivery is appropriately managed to meet the device's needs.
7. **Future-Proofing:** As devices evolve and their power requirements change, power negotiation allows for compatibility with future devices. This means that chargers and devices designed today will continue to be useful as new technologies emerge.

USB PD power negotiation is fundamental to the technology's ability to provide a flexible, safe, and efficient charging solution across a broad spectrum of devices.

7. Conclusion

By addressing the growing demand for higher power levels and more efficient charging solutions, USB PD has established itself as a cornerstone of modern electronic device infrastructure. The intricate power negotiation stack, which facilitates intelligent communication between devices for optimal power delivery, underscores the technology's commitment to versatility, safety, and efficiency.

The transition from fixed power profiles to flexible power rules, and the introduction of features like Extended Power Range (EPR) and Adjustable Voltage Supply (AVS), highlight the USB PD's adaptability to the evolving landscape of electronic devices. Moreover, the benefits of power negotiation—ranging from optimal power utilization and universal compatibility to enhanced safety and dynamic power adjustment—emphasize the user-centric approach of USB PD

8. References

1. He F. USB Port and power delivery: An overview of USB port interoperabiliy. 2015 IEEE Symposium on Product Compliance Engineering (ISPCE) 20151-20155.
2. Stan C-M, Neacşu D. Role of USB Communication in Modem Engineering Education. 2021 International Symposium on Signals, Circuits and Systems (ISSCS) 2021; 1-4.
3. USB Implementers Forum, USB Power Delivery Specification Revision 2.0, Version 1.3 USB Implementers Forum Inc 2017.