Stardew Valley Networking Report

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Date	Version	Description	Author
07/11/2024	1.0	First Version.	Seed Packets
08/01/2024	2.0	Revised by adding detail to the analysis portion of the document as well as breaking up some of the larger sections for readability. Also added a few more visuals to the document.	Seed Packets

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Project Description Document

1. Introduction

1.1 Purpose of the Document

This document serves as a comprehensive summary detailing team Seed Packets' extensive investigation into the networking protocols employed by the game Stardew Valley. Through meticulous analysis of the game's multiplayer dynamics and network architecture, the document seeks to illuminate the underlying peer-to-peer communication structure utilized within the game. This document is aimed at those interested in gaining insights into gaming network protocols, particularly within the context of Stardew Valley. Moreover, it establishes a foundational reference for future research endeavors and technical analyses, offering a framework and methodologies for examining multiplayer gaming networks comprehensively

1.2 Scope of the Document

This project report comprehensively details the Seed Packet team's extensive exploration of Stardew Valley's network protocols, with a specific focus on the game's intricate multiplayer dynamics. It provides a thorough account of the team's research journey, encompassing the project's objectives, methodologies employed for collecting and analyzing network data using Wireshark, and the validation of initial hypotheses. Moreover, the report delves into the rationale behind selecting Stardew Valley, highlighting its widespread popularity and discussing preliminary research conducted prior to the investigation. It includes a compilation of essential references and definitions pertinent to the research context.

Furthermore, beyond mere theoretical exploration, this document endeavors to illustrate the practical application of existing network protocols within the realm of indie game development. By elucidating how these protocols are effectively utilized and optimized, especially in facilitating multiplayer functionalities, it bridges the gap between theoretical knowledge and its real-world implementation. This approach not only enhances understanding of the technical intricacies involved in game networking but also positions the document as a valuable resource for researchers and developers alike who are engaged in advancing the field of multiplayer gaming technologies.

1.3 References

Reference Title/Name	Date	Version
Wireshark Network Protocol Analyzer Open-Source Software - https://www.wireshark.org/	07/11/2024	4.2.5
Wireshark User's Guide - https://www.wireshark.org/docs/wsug_html_chunked/	07/11/2024	4.3.0
Requests For Comments (RFCs) - https://www.rfc-editor.org/	07/12/2024	N/A
Stardew Valley Website - https://www.stardewvalley.net/	07/13/2024	N/A
Stardew Valley Wiki - https://stardewvalleywiki.com/	07/14/2024	N/A
How to Detect P2P - https://www.firewall.cx/	07/14/2024	N/A

1.4 Definitions, Acronyms, and Abbreviations

Term	Abbreviation / Acronym	Definition
Wireshark	Wireshark	Wireshark is an open-source network protocol analyzer. It is a widely used software to analyze real-time and recorded network traffic.
Requests for Comments	RFCs	RFCs describe the protocols and recommended practices that standardize networking within and among networks.
Stardew Valley	Stardew	A popular, indie farming game that is mainly single player, but provides multiplayer features.
Peer-to-Peer Architecture	P2P	A decentralized network structure where each participant (peer) can act as both a client and a server, sharing resources and communicating directly with other peers without relying on a centralized server.
Client-Server Architecture	Client-Server Architecture	A network structure where clients (user devices) request services and resources from centralized servers, which manage and fulfill these requests.
Concerned Ape	Eric Barone	The developer of Stardew Valley.
Seed Packets	Seed Packets	The team's name for Savannah Stephenson, Malak Mahdy, and Chantey Baca.
Independent Video Game	Indie Game	A video game created by independent developers, often with a smaller budget and without the financial support of a large publisher. Typically associated with greater creative freedom and unique art styles.
Worldo	World	A virtual environment, or game instance, which allows for other players to join for live engagement
Host	Host	The individual who initializes/creates and manages the game session or virtual environment, allowing others to join and participate
World of Warcraft World	WOWW	The protocol developed by the massively multiplayer online video game, World of Warcraft, to connect users to their servers.
Transmission Control Protocol	TCP	A standard communication protocol that ensures reliable, ordered, and error-checked delivery of data over networks via a three-way handshake.
User Diagram Protocol	UDP	A lightweight communication protocol that offers connectionless transmission of data packets without guaranteeing delivery or ensuring packet order.
RakNet	RakNet	A networking engine that provides reliable UDP data transmission, supporting features like packet ordering, reliability, and congestion control for multiplayer games and applications.
Transport Layer Security	TLS	A cryptographic protocol designed to provide secure communication over a computer network by encrypting

		data and ensuring its integrity and confidentiality,

2.   Game Choice

2.1   Description

Seed Packets selected Stardew Valley, an indie game that immerses players in a farm life simulation role-play experience. Initially released on February 22, 2016, Stardew Valley has since undergone six major updates, notably introducing multiplayer functionality in the 1.3 update released on August 1, 2018 (Stardew Valley Wiki). Developed solely by Eric Barone, who meticulously crafted the game's pixel art, dialogue, and code, Stardew Valley stands as a testament to Barone's singular dedication and creative prowess within the indie game development landscape. The game has garnered widespread acclaim for its engaging gameplay mechanics and charming art style, appealing to both casual gamers and simulation enthusiasts alike. Its vibrant community has flourished over the years, fostering a culture of sharing mods, tips, and personal in-game anecdotes that enrich the overall player experience and contribute to the game's enduring popularity and community-driven longevity.

In the game the player is working as a corporate shill, when suddenly they get a letter that they have inherited their late Grandfather's farmland in Stardew Valley, a quaint coastal town. This narrative sets the stage for a transformative journey from a mundane corporate life to a fulfilling rural existence, offering players a sense of escape and achievement. The game goes beyond farming, allowing the player not only to plant seasonal crops but to raise animals, go fishing, craft items, explore the mines, and romance their fellow townsfolk. Each activity is designed with depth and attention to detail, ensuring that players remain engaged and invested in their virtual lives. The inclusion of various festivals and events throughout the in-game year adds a dynamic aspect to the gameplay, encouraging players to plan and participate in communal activities, thereby fostering a sense of belonging within the game's world. This diversity in gameplay elements makes Stardew Valley an engaging and multifaceted experience, appealing to a broad audience with varied interests. Moreover, the game's music and sound design contribute significantly to its relaxing and immersive atmosphere, providing a soothing backdrop to the players' activities.

2.2   Developer

Stardew Valley was developed by Concerned Ape, the alias for Eric Barone, who single-handedly crafted the entire first version of the game. From the charming pixel art that defines its visual appeal to the intricately written in-game dialogue and the underlying code that brings the world to life, Barone was the sole creator responsible for every aspect of Stardew Valley's initial creation. His dedication extended to programming the game in C# using the Microsoft XNA framework, a choice favored among indie developers for its comprehensive tools tailored to developing sophisticated and polished games. This framework empowered Barone to not only realize his creative vision but also to establish Stardew Valley as a beloved indie title known for its immersive gameplay and nostalgic aesthetic.

However, in 2021, Barone decided to migrate the game to MonoGame. According to Barone, this migration was intended to "futureproof the game and allow mods to access more than 4 gigs of RAM," which was a significant improvement for the modding community and the game's overall performance (PC Gamer). The transition to MonoGame meant that the game could continue to evolve and grow, meeting the needs and expectations of its dedicated player base. (https://www.pcgamer.com/stardew-valley-update-futureproofs-the-game-with-improved-modding-support/)

The development journey of Stardew Valley did not stop at its initial release. One of the major updates to the game was the addition of multiplayer functionality. Barone had expressed that the task of coding multiplayer features was daunting and described the prospect of it as "really unpleasant." Recognizing the complexity and technical challenges involved, Barone enlisted the help of Chucklefish, the game's publisher. Up until that point, Chucklefish had primarily been responsible for administrative and marketing tasks. However, for the development of multiplayer, they subcontracted the task to another party, bringing in additional expertise to ensure the successful

implementation of this new feature (https://www.gq.com/story/stardew-valley-eric-barone-profile). The transition to multiplayer was a significant milestone for Stardew Valley. It not only expanded the game's functionality, allowing players to share their farming adventures with friends, but also required overcoming substantial technical hurdles. This collaborative effort was crucial in maintaining the game's high standards and ensuring that the multiplayer experience was smooth and enjoyable for players.

Beyond the technical aspects, the addition of multiplayer in Stardew Valley transformed the gameplay experience fundamentally. It introduced cooperative play, enabling friends to collaborate in cultivating and overseeing their farms, pooling resources, and participating jointly in various in-game activities and seasonal events. This innovative feature not only fostered teamwork and camaraderie among players but also introduced a social dimension that significantly enriched the game's appeal and replayability.

The multiplayer update underscored Eric Barone's dedication to enhancing Stardew Valley continuously. It reflected his responsiveness to the community's feedback and desires, demonstrating a commitment to expanding the game's scope and ensuring its longevity. By introducing multiplayer functionality, Barone not only catered to a growing demand for collaborative gaming experiences but also solidified Stardew Valley's position as a dynamic and beloved indie game that continues to captivate and engage players worldwide.

Stardew Valley's evolution from a solo-developed project to a beloved multiplayer game stands as a testament to Eric Barone's visionary approach and unwavering dedication. Barone's journey showcases not only his technical prowess but also his adaptability and willingness to embrace collaboration. By expanding Stardew Valley from its humble beginnings as a single-player experience to a vibrant multiplayer community, Barone has underscored his commitment to innovation and growth in indie game development. His ability to navigate the complexities of expanding gameplay dynamics while maintaining the game's charm and appeal has firmly established Stardew Valley as a standout title that continues to resonate deeply with players worldwide.

2.3   Choice Reasoning

Seed Packets chose Stardew Valley as their research subject due to the active involvement and enthusiasm of two team members, Savannah Stephenson and Malak Mahdy, who are avid players of the game. Their existing familiarity and passion for Stardew Valley sparked their interest in analyzing its networking protocols. The recent addition of multiplayer and cooperative play modes in Stardew Valley presented a compelling opportunity for Seed Packets to investigate significant changes in the game's architecture. This research not only aligned with their academic interests but also provided a deeper motivation to explore the technical complexities behind a game they deeply admire, ensuring a comprehensive and insightful investigation into its networking dynamics.

2.4   Demographics

Stardew Valley has earned widespread acclaim as a 'cozy game' in online circles, standing in stark contrast to the high-intensity environments of first-person shooters or demanding role-playing epics. Its gameplay revolves around setting manageable objectives that provide a gratifying sense of achievement without overwhelming players. Succeeding in Stardew Valley hinges not on extraordinary prowess or endless practice, but on adeptly managing one's farm and engaging in the myriad activities the game offers. The introduction of multiplayer mode marked a significant transformation, turning Stardew Valley from a solitary retreat into a laid-back social hub where friends can leisurely engage together. This evolution has significantly broadened the game's appeal, resonating particularly with casual gamers seeking a tranquil and enjoyable escape from the pressures of competitive gaming landscapes.
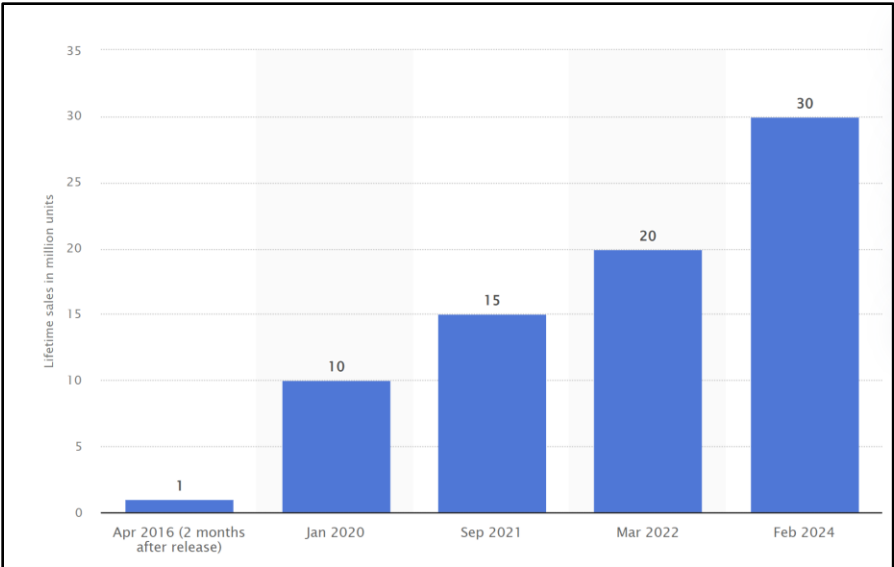
2.5 Popularity

Stardew Valley Sale Statistics

Stardew Valley has seen an extraordinary rise in popularity since its launch in 2016. Initially, the game made waves by selling 500,000 copies within a mere two weeks of its release (https://www.gq.com/story/stardew-valley-eric-barone-profile), setting a strong foundation for its future. Over the years, Stardew Valley's popularity has only intensified, with sales steadily climbing to surpass a remarkable milestone of over 30 million copies sold by February 2024. This sustained success underscores the game's enduring charm and its ability to attract a diverse audience, solidifying its position as a beloved title in the gaming community.

3. Networking Pre-Research

3.1 Co-Op Developer
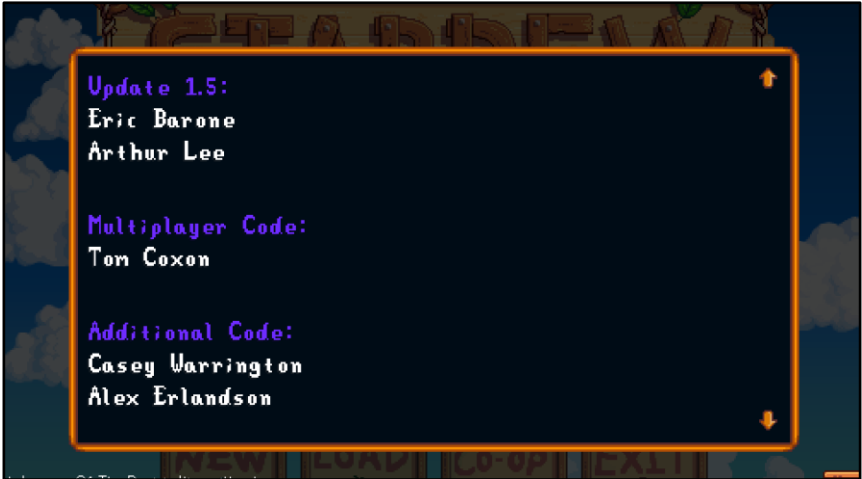
Stardew Valley Game Credits

The Stardew Valley Game Credits reveal that developer Tom Coxon was responsible for writing the multiplayer code, a pivotal addition introduced in late 2018. Despite Coxon's credited role, specific details about the technical intricacies involved in implementing co-op gameplay or the specific computer networking protocols utilized remain sparse. Interviews with the developers have clarified that Eric Barone, under his alias Concerned Ape, did not personally undertake this aspect of development. As Barone himself noted, "I could have learned it and done it myself, but it would have taken three more years to do this." This collaboration underscores the significant challenges and extensive time investment required to integrate multiplayer functionality into an established game framework like Stardew Valley.

3.2   Co-Op Methods Pre-Research

Based on firsthand user experience, Seed Packets initially hypothesized that Stardew Valley employs a peer-to-peer-like structure for its multiplayer functionality. This hypothesis was formulated during their cooperative play sessions, where it became apparent that rather than centralizing all players on a server, the game facilitates direct communication between players' devices. This decentralized approach bears resemblance to a peer-to-peer architecture, suggesting that interactions and game mechanics are supported through direct connections between individual players rather than relying solely on a centralized server infrastructure.

To delve deeper into their hypothesis, Seed Packets meticulously conducted multiple sessions in Stardew Valley's multiplayer cooperative mode. During these sessions, they engaged in various direct-contact tasks while simultaneously recording network packets using Wireshark. The primary goal was to scrutinize the packet data for discernible patterns that align with typical characteristics of peer-to-peer architectures. Through this detailed analysis of network traffic, Seed Packets aimed to arrive at a conclusive determination regarding the validity or potential falsification of their initial hypothesis concerning the game's networking structure.

4.   Data Collection Process

4.1   Set Up

All applications that require any form of internet or network connection was shut down. This prevents any confusion during analysis and ensures the integrity of the resulting packets. This initial step is crucial in collecting appropriate and applicable data to properly investigate Stardew Valley's network architecture and packet usage.

Wireshark was activated before running Stardew Valley. All members of Seed Packets ensured that there were no packets being captured, to guarantee all network applications were shut down. Once Wireshark was correctly activated and no network packets were detected, all members of Seed Packets started the Stardew Valley application on the same device that Wireshark is running on.

4.2   Co-Op

Savannah Stephenson, Seed Packets member, created a Stardew Valley world. The remaining Seed Packets members, Chantey Baca and Malak Mahdy joined the world created by Savannah Stephenson.

Once all members of Seed Packets were able to locate each other on the newly-created world, they performed various tasks that required other players to complete. This included, but is not limited to: swapping items, selling items, and conversing via the in-game chat. During the active-engagement period, members took screen captures of the Stardew Valley world to document the various multiplayer actions taken.

Item Exchange Screenshot

Once the Seed Packets team performed all possible multi-player tasks within a 40-minute time frame, the world was shut down by Savannah Stephenson, and all members deactivated the Wireshark packet capture. Each member saved their packet captures and placed them into a shared folder for analysis.

Further examination of the protocols was taken, and the team thoroughly researched any strange or noticeable patterns and compared each member's captures to one another. The focus was mainly comparing Savannah Stephenson's packets to Malak Mahdy's and Chantey Baca's, as Stephenson was the host, while Baca and Mahdy were members.

5.   Data Analysis

5.1   Background

Upon delving into the Stardew Valley application's origins, it becomes clear there is scarcity of detailed information about its development process. This characteristic is commonly observed in indie games, where creators often maintain a level of secrecy or limited disclosure about their technical implementations. The lack of comprehensive technical documentation necessitated an innovative approach to the Seed Packets team's analysis. In response, the team relied on informed conjectures derived from extensive external research and meticulous examination of individual Wireshark packet captures. These efforts were crucial in piecing together insights into the game's network architecture and multiplayer functionalities, shedding light on its operational intricacies despite the inherent challenges posed by limited available data.

5.2   Protocols Found

Protocol	Description	Capture Found In
RakNet	Raknet is a reliable UDP transport protocol that is generally used for communication between game clients and servers (https://github.com/b23r0/rust-raknet)	Savannah, Chantey
Syslog	Syslog is a protocol that computer systems use to send event data logs to a central location for storage. Logs can then be accessed by analysis and reporting software to perform audits, monitoring, troubleshooting, and other essential IT operational tasks.	Savannah, Malak, Chantey

	The go-to logging method since the 1980s, the syslog protocol has maintained its popularity through its ease of use, making it simple and straightforward to transport event log messages (https://www.sumologic.com/syslog/).	
TCP	Transmission Control Protocol (TCP) is a communications standard that enables application programs and computing devices to exchange messages over a network. It is designed to send packets across the internet and ensure the successful delivery of data and messages over networks (https://www.fortinet.com/resources/cyberglossary/tcp-ip#:~:text=What%20is%20TCP%3F,exchange%20messages%20over%20a%20network).	Savannah, Malak, Chantey
TLSv1.2	TLS 1.2 is simply an upgraded form of TLS 1.1. TLS 1.2 was released in 2008, offering improved security, and was designed for both high performance and improved reliability. To accomplish this, it relies on a combination of symmetric and asymmetric cryptography (https://blog.gigamon.com/2021/07/14/what-is-tls-1-2-and-why-should-you-still-care/).	Savannah, Malak, Chantey
SSDP	SSDP (Simple Service Discovery Protocol) is a network protocol used in small networks, including home networks, to advertise and discover network services primarily supported by the Universal Plug-and-Play (UPnP) architecture. SSDP is an HTTPU-based textual protocol that uses XML. It exchanges messages using UDP datagrams (https://stormwall.network/knowledge-base/protocol/ssdp).	Savannah, Malak, Chantey
DNS	The Domain Name System (DNS) protocol is a process that allows internet users to navigate the internet using hostnames instead of numeric IP addresses (https://www.ibm.com/topics/dns-protocol).	Savannah, Malak, Chantey
ICMP	The Internet Control Message Protocol (ICMP) is a network layer protocol used by network devices to diagnose network communication issues. ICMP is mainly used to determine whether or not data is reaching its intended destination in a timely manner (https://www.cloudflare.com/learning/ddos/glossary/internet-control-message-protocol-icmp/#:~:text=Copy%20article%20link-,What%20is%20the%20Internet%20Control%20Message%20Protocol%20(ICMP)%3F,destination%20in%20a%20timely%20manner).	Savannah, Malak, Chantey
ARP	Address Resolution Protocol (ARP) is a protocol or procedure that connects an ever-changing Internet Protocol (IP) address to a fixed physical machine address, also known as a media access control (MAC) address, in a local-area network (LAN) (https://www.fortinet.com/resources/cyberglossary/what-is-arp).	Savannah, Malak, Chantey
UDP	User Datagram Protocol (UDP) is a communications protocol for time-sensitive applications like gaming, playing videos, or Domain Name System (DNS) lookups. UDP results in speedier communication because it does not spend time forming a firm connection with the destination before transferring the data (https://www.fortinet.com/resources/cyberglossary/user-datagram-protocol-udp#:~:text=User%20Datagram%20Protocol%20(UDP)%20is,destination%20before%20transferring%20the%20data).	Savannah, Malak, Chantey
TLSv1.3	The TLS Version 1.3 protocol is a major revision to the TLS protocol that is intended to provide better security and improve handshake	Savannah, Malak, Chantey

	performance (https://www.ibm.com/docs/en/zos/2.4.0?topic=security-using-tlsv13-protocol-support).	
MDNS	Multicast DNS (mDNS) is a protocol within the DNS framework that enables network services and devices to be discovered without a traditional DNS server. It operates within a local network and allows devices to perform DNS-like operations in the absence of a DNS server, thus facilitating zero-configuration networking (Zeroconf) (https://medium.com/@contact_45426/understanding-dns-and-mdns-5aacc994f30f).	Savannah, Malak, Chantey
ICMPv6	The Internet Protocol version 6 (IPv6) uses the Internet Control Message Protocol (ICMP) as defined for IPv4 [RFC-792], with a number of changes. The resulting protocol is called ICMPv6 (https://datatracker.ietf.org/doc/html/rfc4443).	Savannah, Malak, Chantey
ICMPv3	Version 3 adds support for "source filtering", that is, the ability for a system to report interest in receiving packets *only* from specific source addresses, as required to support Source-Specific Multicast [SSM], or from *all but* specific source addresses, sent to a particular multicast address (https://datatracker.ietf.org/doc/html/rfc3376)	Savannah
R-GOOSE	R-GOOSE (Routable Generic Object-Oriented Substation Event) is a protocol used in the electrical utility industry for fast and reliable communication within substations and across substations using Ethernet networks. (Protocols/IEC61850GOOSEGSE - Wireshark Wiki)	Savannah
QUIC	QUIC (Quick UDP Internet Connections) is a transport layer network protocol designed by Google to improve the performance of connection-oriented web applications. It provides reduced latency and bandwidth requirements compared to traditional protocols like TCP. (RFC 9000 - QUIC: A UDP-Based Multiplexed and Secure Transport (ietf.org))	Savannah, Chantey
HTTP	The Hypertext Transfer Protocol (HTTP) is an application protocol for distributed, collaborative, hypermedia information systems. It is the foundation of data communication for the World Wide Web. (Hyper_Text_Transfer_Protocol - Wireshark Wiki)	Savannah, Malak, Chantey
OCSP	The Online Certificate Status Protocol (OCSP) is an Internet protocol used for obtaining the revocation status of an X.509 digital certificate. It was created as an alternative to Certificate Revocation Lists (CRLs). (What Is OCSP and How Does It Work? (techtarget.com))	Savannah, Chantey
IGMPv2	Internet Group Management Protocol version 2 (IGMPv2) is a protocol used by IPv4 systems to report their IP multicast group memberships to neighboring routers. (RFC 2236 - Internet Group Management Protocol, Version 2 (ietf.org))	Malak
TLSv1	TLS version 1.0 is a security protocol designed to provide privacy and data integrity between two communicating computer applications. It is now considered outdated and has been replaced by newer versions such as TLS 1.2 and TLS 1.3. (RFC 2246 - The TLS Protocol Version 1.0 (ietf.org))	Chantey
IGMPv3	Internet Group Management Protocol version 3 (IGMPv3) adds support for source filtering, allowing a system to report interest in receiving packets only from specific source addresses or from all but specific source addresses. (ietf.org/rfc/rfc3376.txt)	Chantey, Savannah
LLMNR	Link-Local Multicast Name Resolution (LLMNR) is a protocol that enables name resolution in scenarios where conventional DNS name resolution is not possible. It allows both IPv4 and IPv6 hosts to perform	Chantey, Savannah

	name resolution for hosts on the same local link. ([Link-local Multicast Name Resolution (LLMNR) - Microsoft Research](#))	
DHCP	Dynamic Host Configuration Protocol (DHCP) is a network management protocol used to automate the process of configuring devices on IP networks. It dynamically assigns IP addresses to devices and provides essential network configuration details. ([DHCP - Wireshark Wiki](#))	Chantey
NBNS	NetBIOS Name Service (NBNS) is a protocol used in Windows-based networks to allow computers to register and resolve NetBIOS names to IP addresses. It is part of the NetBIOS over TCP/IP suite. ([NetBIOS/NBNS - Wireshark Wiki](#))	Chantey, Savannah

There are clearly no protocols developed by Stardew Valley, made specifically for the video game. Instead, Stardew Valley has complete reliance on existing protocols. The conclusion that Stardew Valley has not created any protocols is by reviewing the Wireshark captures for any unfamiliar protocols—indeed, none were detected. Additionally, determined through external research, there are no protocols stated to have been created by Concerned Ape or Tom Coxon. This may also be attributed to the fact that it is an independent video game. It is common practice for video games developed by larger corporations to invest in the invention and creation of their own protocols, which are tailored specifically for their needs. A prime example of this is the World of Warcraft protocol, which is World of Warcraft World (WOWW). This contrast between massively multiplayer online games and Stardew Valley creates a deeper understanding of how Stardew Valley takes advantage of the pre-existing protocols.

5.3   TCP Analysis

Stardew Valley relies extensively on the Transmission Control Protocol (TCP) to power its cooperative play mode, leveraging TCP's foundational role within the Internet protocol suite. TCP is specifically engineered to ensure the secure, ordered, and error-checked transmission of data between applications across diverse networks. This protocol achieves reliability by breaking down data into smaller packets, each of which is individually transmitted and subsequently reassembled in the correct sequence upon arrival at its destination. Through mechanisms such as acknowledgments and packet retransmission, TCP guarantees the integrity and precise delivery of data, providing a robust framework for communication.

In the context of video games, TCP's ability to maintain consistent game state synchronization and preserve player actions makes it highly suitable for titles like Stardew Valley. By adopting TCP, Stardew Valley ensures that multiplayer interactions proceed smoothly and predictably, without the complexities of developing custom networking protocols. This pragmatic approach underscores the game's commitment to leveraging established networking standards to enhance gameplay reliability and user experience. Thus, TCP serves as a cornerstone of Stardew Valley's networking infrastructure, supporting its cooperative play mode by facilitating seamless and dependable communication among players.

5.4   UDP Analysis

Stardew Valley's networking framework incorporates both the User Datagram Protocol (UDP) and Transmission Control Protocol (TCP) to optimize its multiplayer experience. UDP, a cornerstone of the Internet protocol suite, prioritizes efficiency by transmitting data swiftly with minimal overhead. Unlike TCP, UDP sacrifices guaranteed delivery, order, and error-checking for speed and low latency, making it ideal for applications where real-time responsiveness is crucial, such as online gaming, video streaming, and VoIP. This protocol's direct approach facilitates rapid packet delivery, ensuring smooth interactions and dynamic gameplay experiences in Stardew Valley's multiplayer mode.

In contrast to TCP's role in ensuring reliable transmission of critical game state updates and player actions, UDP's usage pattern in Stardew Valley emphasizes handling real-time interactions like player movements and non-critical

updates. While UDP's occasional data loss tolerance may lead to slight inconsistencies, its ability to swiftly deliver packets supports seamless gameplay interactions among peers. This strategic utilization of both protocols enhances the game's overall performance, maintaining a balance between responsiveness and reliability throughout cooperative play sessions. Thus, Stardew Valley leverages UDP's strengths to enrich its multiplayer dynamics, offering players an engaging and interactive farming experience with friends.

5.5 RakNet Analysis

The third significant discovery in Seed Packet's members' Wireshark capture analysis centered around RakNet. RakNet stands out as a pivotal high-level network engine extensively utilized in multiplayer gaming contexts. Specifically engineered for game development, RakNet boasts a comprehensive suite of features including reliable UDP message transmission, object replication, remote procedure calls (RPCs), and automated packet sequencing and prioritization. Its robust capabilities simplify the integration of multiplayer functionalities, accommodating diverse architectural needs from peer-to-peer setups to traditional client-server models. Renowned for its scalability, efficiency, and seamless integration capabilities, RakNet remains a favored solution among both indie and commercial game developers seeking to enhance their games with reliable and efficient networking capabilities

5.6 TLS Analysis

Along with the major protocols seen in abundance above, there were some minor protocols captured during Seed Packet's research. One of the protocols was Transport Layer Security or TLS. TLS plays a crucial role in securing communication between players in Stardew Valley's network protocols. TLS is a widely adopted protocol that provides privacy and data integrity between communicating applications over a network. In the analysis of the network packets using Wireshark, the team identified the use of TLS, indicating that the game employs encryption to protect sensitive information exchanged during multiplayer sessions. This is particularly important in a peer-to-peer architecture, where data can be potentially exposed. By using TLS, Stardew Valley enhances the security between players, ensuring that exchanges remain confidential. While the game does rely on existing protocols like TCP and UDP for data transmission, TLS adds an additional layer of security by encrypting the data packets. This combination of reliable transmission protocols helps to safeguard the integrity and privacy of player interactions, contributing to a safer and more trustworthy gaming experience.

5.7 ARP Analysis

The ARP (Address Resolution Protocol) is used for resolving network layer addresses into link layer addresses. In the context of playing Stardew Valley, ARP packets in the Wireshark capture indicate that devices on the player's network are performing normal network operations to communicate with each other. The main reason that ARP is most likely present in the capture is device discovery and communication. When the computer (or console) is running Stardew Valley and needs to communicate with another device on the local network (such as an internet router), it uses ARP to find the hardware (MAC) address associated with the IP address of the target device. It's clear to see this behavior in the 'info' section of the packet header in Wireshark as the packet often is asking a direct question: "Who has 192.168.1.4? Tell 192.168.1.1".

When analyzing the ARP packets found in one of Seed Packet's Wireshark captures there were two distinct packet behaviors. The first behavior is when the ARP packet is communicating between the user's machine and the internet provider. Seen below:

```
447 67.932374    Netgear_5b:9e:84    Intel_e7:e9:15      ARP    42 Who has 192.168.1.4? Tell 192.168.1.1
448 67.932432    Intel_e7:e9:15      Netgear_5b:9e:84    ARP    42 192.168.1.4 is at b0:7d:64:e7:e9:15
```

The second behavior is when the ARP packet is communicating with Broadcast. The broadcast address is a special MAC address that signifies that the packet should be delivered to all devices on the local network segment. An example of this packet type is seen below:

```
1756 316.789671   76:37:32:f6:18:55   Broadcast          ARP    42 Who has 192.168.1.1? Tell 192.168.1.3
```

In regards to co-op and this Broadcast packet, when the host device communicates with remote players, the data must first be sent to the hosts local router, which then forwards it over the internet. The host device uses ARP to find the MAC address of the router to send these packets to it. It's also possible that when establishing a connection to a

game server or another player, the device might perform ARP requests to ensure it has up-to-date information about the local network devices before routing the traffic to remote destinations.

5.8   Syslog Analysis

Syslog is a standard protocol used for logging system messages and events.

In the body of a Syslog packet, we can clearly see that the syslog packets in our Wireshark capture are being generated by RakNet as the syslog messages are marked [RakNetInternal] as seen below:

```
Frame 11284: 246 bytes on wire (1968 bits), 246 bytes captured (1968 bits) on interface \Device\NPF_{196EFC97-0BB8-4020-8750-196B09BC321A}, id 0
Ethernet II, Src: Intel_e7:e9:15 (b0:7d:64:e7:e9:15), Dst: Netgear_5b:9e:84 (9c:c9:eb:5b:9e:84)
Internet Protocol Version 4, Src: 192.168.1.4, Dst: 77.79.249.151
User Datagram Protocol, Src Port: 50460, Dst Port: 514
Syslog message: LOCAL0.INFO: 1 2024-07-10T00:53:23.496491+00:00 sav galaxy_peer 5d5faf38 galaxy1 - (1.148.3.0, 48767653913349277) [RakNetInternal] Sent ID_CONNECTION_REQUEST_ACCEPTED to 24.155.200.67:62546, ID:
    1000 0... = Facility: LOCAL0 - reserved for local use (16)
    .... .110 = Level: INFO - informational (6)
  > Message: 1 2024-07-10T00:53:23.496491+00:00 sav galaxy_peer 5d5faf38 galaxy1 - (1.148.3.0, 48767653913349277) [RakNetInternal] Sent ID_CONNECTION_REQUEST_ACCEPTED to 24.155.200.67:62546, ID: 57732842831738548
```

The body of the packet is sending an ID_CONNECTION_REQUEST_ACCEPTED regarding a specific IP address. This shows that it is the RakNet protocol that is handling the communication between multiplayer clients and the server. The internal messages are part of the protocol used to manage connections, synchronize game state, and ensure reliable communication between players. Additionally, Raknet might be sending internal messages to maintain the state of connection, handle keep-alive signals, manage player connections and disconnections, and ensure data integrity.

The presence of these RakNet internal messages in the syslog packets captured by Wireshark highlights the role of RakNet in managing multiplayer game networking. These messages provide insights into the connection management and synchronization processes that are vital for multiplayer gaming.

5.9   ICMP Analysis

ICMP (Internet Control Message Protocol) packets are commonly seen in network traffic captures and serve various purposes in network communication. ICMP is used to convey error messages and diagnostics, such as destination unreachable, time exceeded, or redirect messages. These messages help identify and troubleshoot network issues that could affect game connectivity and performance. The two ICMP packets found on Savannah's Wireshark capture clearly capture this phenomenon seen below:

```
  865 146.055043    147.75.193.65     192.168.1.4      ICMP      590 Destination unreachable (Port unreachable)
11235 841.822773    100.93.160.195    192.168.1.4      ICMP       72 Time-to-live exceeded (Time to live exceeded in transit)
```

ICMPv6 (Internet Control Message Protocol for IPv6) is the version of ICMP used in IPv6 networks. The packets below are labeled "Multicast Listener Report Message v2," this type of packet is a part of the Multicast Listener Discovery (MLD) protocol, which is used by IPv6 routers to discover multicast listeners on a directly attached link:

```
1319 240.946816    fe80::101f:89bb:4fe…  ff02::16           ICMPv6          90 Multicast Listener Report Message v2
1347 245.428475    fe80::101f:89bb:4fe…  ff02::16           ICMPv6          90 Multicast Listener Report Message v2
```

This specific message is sent by a host to inform the local router that it wants to receive multicast traffic for specific multicast addresses. This helps routers maintain accurate multicast forwarding tables. A multicast forwarding table is a data structure used by network devices, such as routers and switches, to manage and route multicast traffic efficiently. Multicast traffic involves sending data to multiple recipients simultaneously using a single transmission, which is more efficient than sending separate copies to each recipient.

The ICMPv6 "Multicast Listener Report Message v2" packets in the Wireshark capture are likely produced by the device's operating system, network stack, or other background services as part of normal IPv6 network operations. These packets are used to manage multicast group memberships and ensure efficient network communication. Their presence does not necessarily indicate that the Stardew Valley co-op game is directly using multicast, but rather reflects standard network behavior and management.

5.10   Matching in Game Actions to Packets

During the active cooperative playing time, the Seed Packet team documented the various protocols that appeared during specific actions. While Seed Packet member Savannah Stephenson created the world, all captures were of RakNet. Another instance of multiplayer engagement was through communication via the in-game chat.

Stardew Valley Chat Screenshot

While the Seed Packet members were messaging directly on Stardew Valley, almost all detected packets were consistently TCP. This is quite significant and important to note. As opposed to a mixture of UDP and TCP detections, it became dominantly TCP. TCP is used for messaging, since any loss of integrity would result in a failed outcome. Using UDP for messaging in the game would be a great potential for communication errors and lack of quality, as it is impossible to ensure that both parties are receiving the intended message. The final possible multiplayer action was the swapping of, or gifting of items to another player. This action triggered no unique output—the flood of a mixture of TCP and UDP continued as it previously was.

5.11   Peer-to-Peer Analysis

The substantial prevalence of both Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) evident across all three captures provides compelling support for the Seed Packet team's hypothesis regarding Stardew Valley's peer-to-peer architecture. External research further reinforces that the abundance of TCP and UDP signals a peer-to-peer configuration rather than a client-server model. In Stardew Valley's cooperative play mode, the host acts as the server, facilitating interactions among players who function as clients. This dynamic can flexibly adjust during multiplayer activities such as item exchanges, where roles may shift depending on the specific tasks underway. This adaptive networking structure highlights the game's robust capability to seamlessly accommodate diverse player interactions within its peer-to-peer framework, emphasizing its versatility and effectiveness in multiplayer gameplay scenarios.

```
2499 85.831066      192.168.0.8          23.205.110.146      TLSv1.3   1
2500 85.831293      192.168.0.8          23.205.110.146      TCP       1
2501 85.831293      192.168.0.8          23.205.110.146      TCP       1
2502 85.831293      192.168.0.8          23.205.110.146      TLSv1.3
2503 85.831362      192.168.0.8          23.205.110.146      TLSv1.3
2504 85.864796      23.205.110.146       192.168.0.8         TCP
2505 85.867106      23.205.110.146       192.168.0.8         TCP
2506 85.901767      23.205.110.146       192.168.0.8         TLSv1.3
2507 85.901767      23.205.110.146       192.168.0.8         TLSv1.3
2508 85.901857      192.168.0.8          23.205.110.146      TCP
```

Based on the comprehensive network traffic analysis conducted, it was clearly observed that the communication patterns between the source IP address 23.205.110.146 and the destination IP address 192.168.0.8 predominantly consisted of UDP (User Datagram Protocol) conversations. This significant finding strongly corroborates the Seed Packets team's hypothesis regarding the peer-to-peer (P2P) architecture employed in Stardew Valley's multiplayer system. Further detailed analysis has affirmed that multiple UDP conversations are a defining trait of P2P applications, underscoring the consistency and reliability of the observed network behavior with respect to the team's initial conclusions and research.

5.12   TCP and UDP Teamwork

TCP's role in Stardew Valley ensures the reliable and orderly transmission of critical data essential for maintaining consistency in cooperative play sessions. It meticulously manages game state synchronization and player actions, providing a robust foundation for gameplay integrity. Conversely, UDP is adept at handling real-time communication tasks such as player movements and non-critical updates. Despite its lower integrity and potential for packet loss, UDP excels in facilitating swift responses and fluid gameplay interactions between peers.

In Stardew Valley's peer-to-peer architecture, where the host doubles as the server, TCP likely prioritizes the management of crucial gameplay elements to ensure all players receive synchronized updates without discrepancies. Meanwhile, UDP enhances performance by enabling rapid, real-time exchanges among players, promoting seamless interaction within the game's cooperative framework. This strategic blend of TCP for reliability and UDP for responsiveness optimizes the overall gaming experience, offering players a balanced mix of dependable data transmission and fluid gameplay dynamics during cooperative play sessions.

6.   Conclusion

Through hands-on exploration of Stardew Valley's network protocols, the Seed Packets team not only gained valuable insights into the game's multiplayer dynamics and network architecture but also confirmed their initial hypothesis regarding its peer-to-peer structure. In a comprehensive thirty-minute game session designed for analysis using Wireshark, the team meticulously examined captured network packets. Their analysis revealed consistent patterns indicative of peer-to-peer communication, where direct links between players' devices facilitated interactions such as in-game chat, item sales, and exchanges, without the need for a centralized server. This decentralized approach significantly enhances the multiplayer experience by allowing seamless, direct interaction among players

Moreover, the investigation highlighted the strategic utilization of Transmission Control Protocol (TCP) for essential data transmission within Stardew Valley. TCP plays a crucial role in ensuring the dependable and orderly delivery of game state updates and player actions, which are vital for maintaining fairness and synchronization among all players engaged in cooperative play. However, User Datagram Protocol (UDP) was observed managing real-time, less critical interactions like player movements. UDP's emphasis on speed and efficiency, even at the cost

of occasional data loss, optimizes performance in scenarios where immediate responsiveness is prioritized over absolute data integrity. This dual protocol approach effectively balances the requirements of gameplay dynamics in Stardew Valley, enhancing both user experience and technical efficiency.

Furthermore, the team identified RakNet as a key component facilitating features such as reliable UDP message transmission and object replication, which underpin the game's multiplayer functionalities. Additionally, the implementation of Transport Layer Security (TLS) was noted, ensuring encrypted communication to safeguard sensitive player data during gameplay sessions.

In conclusion, this project has yielded deep insights into Stardew Valley's networking system, illustrating how the game optimizes established protocols to deliver a seamless multiplayer experience. By meticulously documenting their methods, experiences, and findings, the Seed Packets team has contributed to a broader understanding of networking protocols in gaming. Their work underscores the effectiveness of leveraging standardized protocols to enhance multiplayer gaming experiences and showcases the application of robust networking solutions in the gaming industry.

Seed Packet Team Gathered Together for a Picture