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Super-peer architectures for distributed computing

Determining the best overall topology for general-purpose distributed computing

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SUPERPEER ARCHITECTURES FOR DISTRIBUTED COMPUTING

Determining the best overall topology for general-purpose distributed computing

Executive Summary

Distributed Computing has been the holy grail of software industry for the last 3 decades, solving problems in domains of business applications, scientific computations and large scale collaborative systems to name a few. Over this period, the architecture of software systems has evolved, typically following the evolution of hardware systems from mainframes in the 70's,client/server systems in the 80's and early 90's, thin-clients in the late 90's and more recent peer-topper distributed systems.

In this whitepaper, we compare and evaluate various software infrastructure topologies with respect to characteristics like scalability, performance, reliability and manageability, among others, with a view towards determining the best overall topology for general-purpose distributed computing and the solution of a wide range of business problems.

Distributes system topologies

Component-based network applications map naturally to business processes that involve an exchange of information among applications running across computer networks. Selection of appropriate system topology is fundamental to the software infrastructure platform enabling such distributed applications. While a distributed application only involves the flow of data, a distributed infrastructure platform needs to support both control and data flow. Control flow can be looked upon as a special flow of packets that enable, regulate and monitor data flow.

In the following sections, we compare the organization of various distributed software system topologies with respect to flow of control and data.

Centralized systems

Centralized systems form the most popular system topology, typically seen as the client/server pattern. All function and information is centralized on a single server (sometimes referred to as the "hub"), with many clients (the "spokes") connecting directly to the server to send and receive information. Both control flow and data flow take place through the central server.

The primary advantage of centralized systems is their simplicity. Because all data is concentrated in one place, centralized systems are easily managed and have no questions of data consistency or coherence. Centralized systems are also relatively easy to secure, since there is only one host to be protected.

The drawback of centralization is that all information resides at the hub. The hub is thus a single point of failure, since if the hub dies then all client applications connected to the hub also die. The hub is also a bottleneck to scalability and performance. While one can introduce redundant hardware and employ better or faster hardware at the hub, this only alleviates the problem and does not solve it completely. Even though the hub-and-spoke architecture has found widespread acceptance in database servers and web-servers, the drawbacks of scalability and fault-tolerance make it unsuitable for general purpose distributed application deployment.

Examples of systems conforming to this centralized topology include J2EE servers and most commercially available web-servers and transaction processing monitors, including Microsoft's MTS.

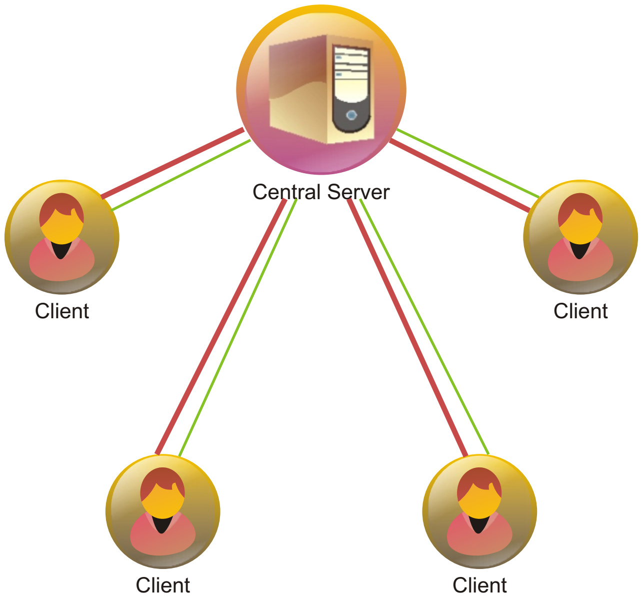

Figure 1: Centralized systems

Pure P2P systems

A primary virtue of pure P2P systems is their scalability; any node can join a network and start exchanging data with any other node. Decentralized systems also tend to be fault tolerant, as the failure or shutdown of any particular node does not impact the rest of the system.

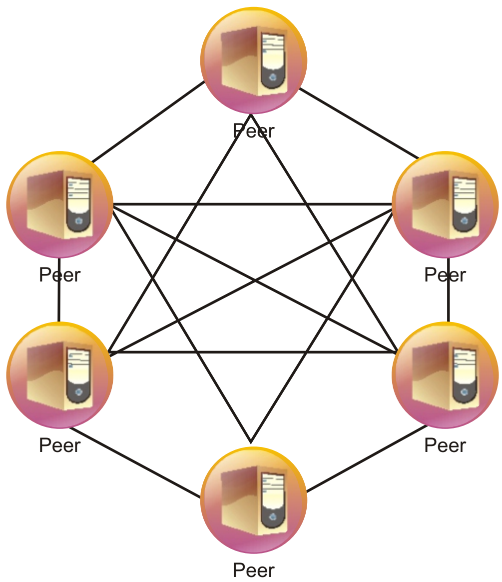

Figure 2: P2P systems

Hybrid P2P systems

In a hybrid peer-to-peer system, the control information is exchanged through a central server, while data flow takes place in a pure peer-to-peer manner as above.

This architecture alleviates the manageability problems of pure P2P systems. The control server acts as a monitoring agent for all the other peers and ensures information coherence.

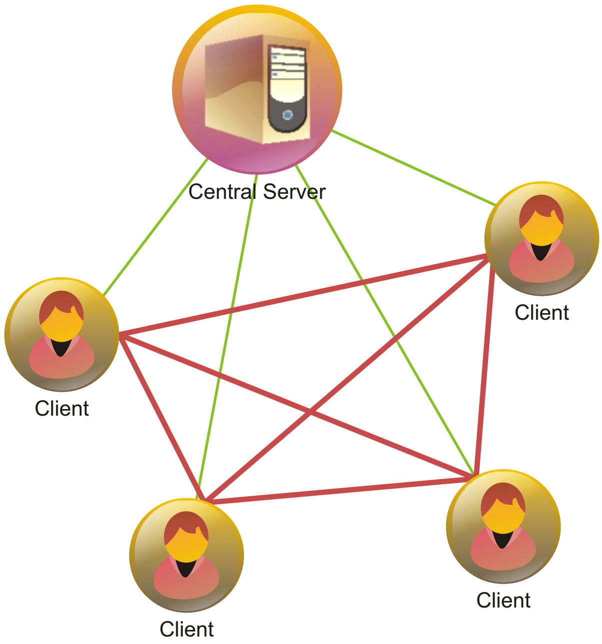

Figure 3: Hybrid peer-to-peer system

The drawbacks associated with control being centrally managed still remain. If the central server goes down, the system looses ability to affect changes in data flow. However, existing applications are not affected by a failure of the central server as the data flow between nodes continues regardless of whether the central server is functional or not.

Peer-to-peer data routing, allows the Hybrid system to offer better scalability than a centralized system; but hybrid systems still suffer from scalability problems for control information that flows through a single node. While Hybrid systems are being effectively used for mission critical applications, the solutions are limited to solve relatively small-scale problems only.

An example of a commercial hybrid P2P system is Groove. Groove implements collaborative project management software in which a central synchronizing server controls all information being exchanged between peers.

Super peer architecture

A new wave of peer-to-peer systems is advancing architecture of centralized topology embedded in decentralized systems; such topology forms a super-peer network.

Reduced time & bandwidth for search: The search is much faster in Super-Peer networks when compared to other topologies, since the system is now broken into a search of information from a smaller set of Super-Peers, each of which have indexed information for their set of peers.

For instance, a search which takes O(N) time on a pure/hybrid P2P network, will take O(N/M) time on a Super-Peer network (where M is the average number of peers connected to a single super-peer). This nearly eliminates the problem of network flooding typically associated with a pure P2P system.

Autonomous Units: The super-peer architecture defines various autonomous units collaborating with each other on the basis of a predefined contract. Each super-peer cluster corresponds to an autonomous unit in the sense that it does not depend on any central server for the exchange of information.

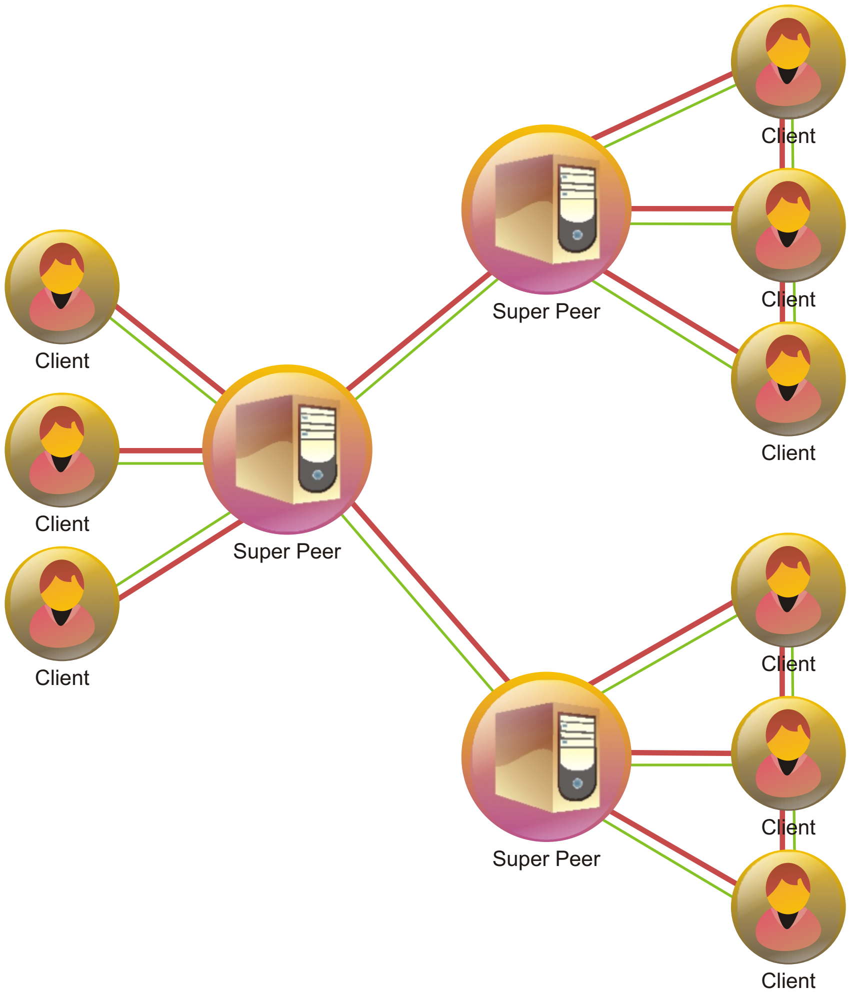

Figure 4: Super peer architecture

Manageability: Super-peers, which are more reliable and trust-worthy peers, can monitor client activity of all peers connected to them. This ensures that malicious activities can be controlled across the network.

Load Balancing: In a pure peer-to-peer network, every peer is given equal responsibility irrespective of its computing/network capabilities. This can quickly lead to deterioration of performance due to network fragmentation as less capable nodes are added.

This problem is alleviated in a super-peer architecture, as only relatively powerful computers with large network bandwidth are promoted to the status of super-peers. This ensures that the super-peer network divides load according to the capability of the peers, leading to overall better performance.

Although super-peer clusters are efficient, scalable and manageable, a super-peer becomes a potential single point of failure for its clients. This problem is overcome via the notion of *super-peer redundancy,* in which fail-over super-peers are defined to automatically take over the job of the primary super-peer in case of failures.

As can be seen from the summary table below, a redundant super-peer architecture, which combines the virtues of both centralized and decentralized systems, is the most suitable topology employed for developing and deploying distributed software systems.

Table 1: Comparison of the topologies

Topology	Manageable	Coherent	Scalable	Reliability
Centralized	Yes	Yes	No	No
De-Centralized	No	No	Yes	Yes
Hybrid P2P	Yes	Yes	Yes	No
Super Peer	Yes	Yes	Yes	Yes

Next generation distributed computing architecture

Combining the Super-Peer topology with the Coarse-grained Component model [1] enables a distributed computing platform for a whole new generation of distributed applications which are more flexible, scalable, and reliable than traditional applications.

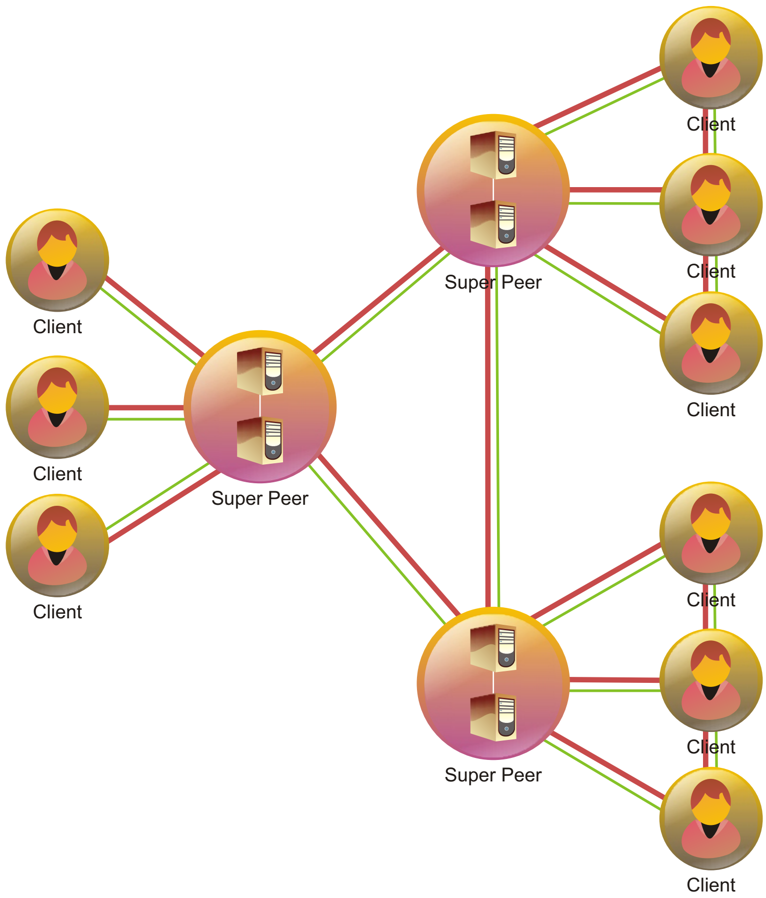

Figure 5: The super peer architecture

The super peer architecture closely maps to real world business processes. Each cluster maps to a business division. Super peers can have well defined protocols for cross cluster communication (acting as firewall for this virtual internet). The adjoining figure illustrates a 2-redundant super peer architecture that alleviates the bottlenecks associated with a super peer being a single point of failure for its clients.

In the following sections, we examine a real-world problem that represents a typical business process and discuss the implementation of this process over multiple software infrastructure system topologies.

Business problem

The problem consists of interaction between a product supplier and one or more customers. Product sales are entered into the system through three order entry channels: the Web site, a store (point of sale) and over the phone. Once and order has been placed it is handled by one of the sales department personnel. The applications corresponding to inventory, price check, tax calculation and credit check are shared across all the departments.

The architectural topology depicting the logical links of information exchanged is shown below. There are 4 departments: sales, internet management, warehouse management, and the finance department. The figure shows the communication links through which data will flow.

The major problem with this solution is scalability, performance and the risk of failure. If a new sales office opens up in some other location, the capacity of the central server has to be increased to support the increased load. Moreover, the performance and quality of service can be questionable.

As an example, if two people in the sales department have to exchange some data, the data transfer takes place through the central server, which leads to degraded performance since the central server is potentially at a different location. Besides, the central server is a single point of failure. For instance, if the power supply of the finance department (which hosts the central server) crashes, all applications across the network come to a standstill.

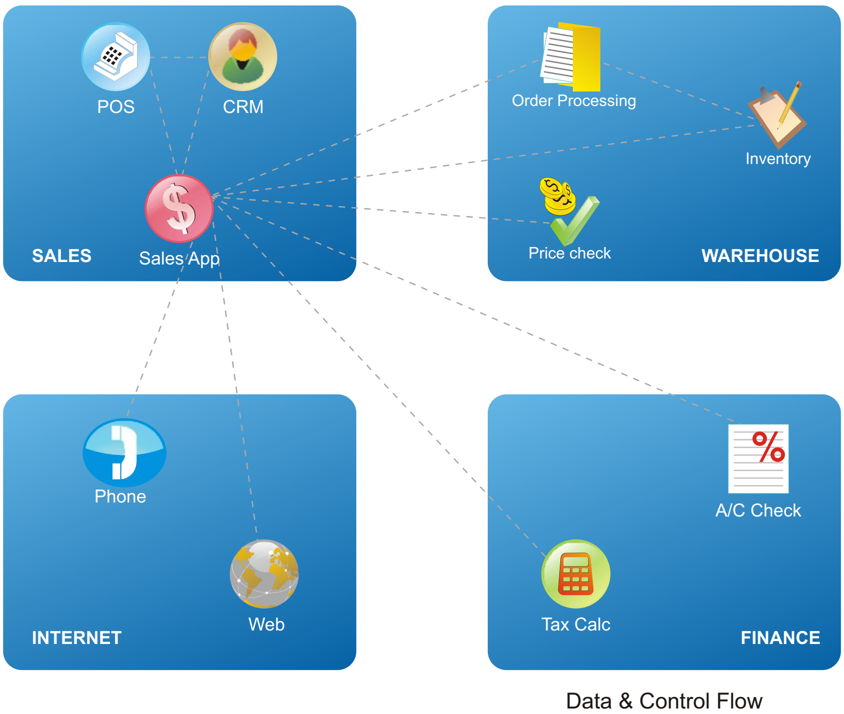

Figure 6: The business problem

In the following sections, we examine how the above problem is solved by each of the software platform architecture approaches previously discussed: Client-Server, Pure Peer-to-Peer, Hybrid Peer-to-Peer and Super-Peer.

Client/Server

In this topology, all internal and external clients and nodes (running proprietary applications) are connected to a central server hosted in the finance department. Control and data flow take place through the central server. Moreover, both inter-departmental and intra-departmental communication also takes place through the central server. The value of this approach is that common applications such as price check, tax calculation and parsing applications can be located at any point in the enterprise and still be accessible by all nodes. Management of the software system is simplified, since there is centralized configuration, administration and security. Since all data gets routed through the central server, the data in the system is consistent and coherent.

Figure 7: Client server configurations

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Pure peer-to-peer topology

This topology is the other extreme of the client/server topology discussed in the previous section. There is no central controller in this topology and all nodes (hosting different applications) are connected to each other in a P2P manner. Both intra and inter departmental communication takes place in a P2P fashion. Hence two people within the sales department as well as across sales and finance departments communicate by establishing direct connections between their desktops. This topology results in very high performance, since data is transferred in a direct P2P fashion. Besides, the system is completely scalable; for instance, if a new sales office is to be added, it can easily become a part of the network.

This topology is also more reliable than the centralized hub-and-spoke topology: a failure in one of the departments does not stop the business processes in other departments; the data exchange among other departments continues unabated. Unlike centralized systems, the failure is not catastrophic in this case.

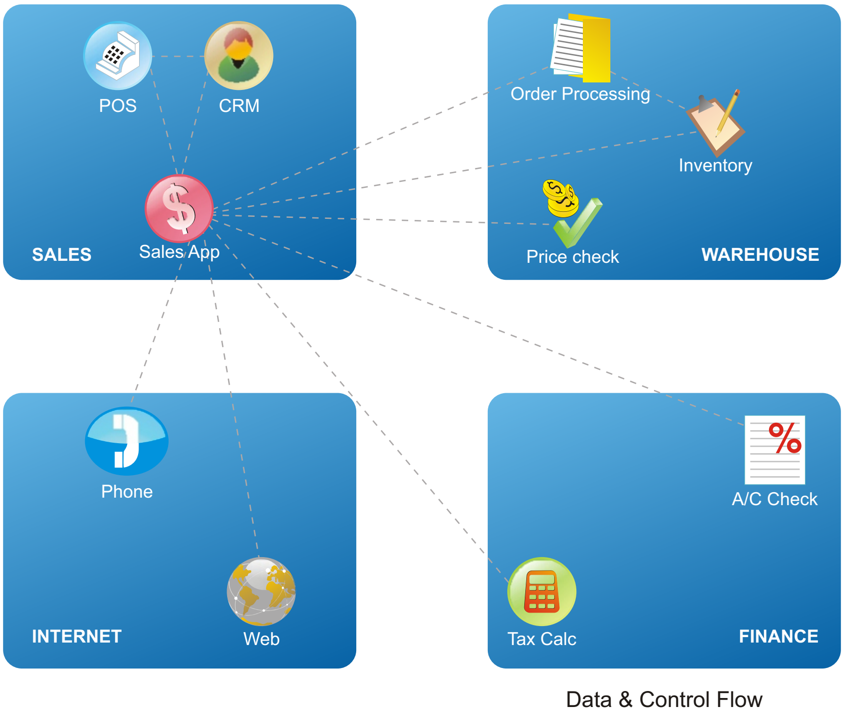

Figure 8: Peer-to-peer topology

However, the pure peer-to-peer approach suffers from some obvious disadvantages. Any node can inject malicious data in the system, which may crash the business process. The data in the network is also not coherent. Since there is no monitoring server, security and configuration become major issues. Fail-over semantics are difficult to lay down in this network, as there is no central server which detects the presence/absence of peer to take necessary action.

Hybrid P2P topology

This topology has a single control server that is hosted by one of the departments, say the finance department. As such, all data flow takes place in a peer-to-peer fashion, leading to a relatively high performance as compared to a centralized system, while the control flow is through a single centralized server.

This topology tries to combine the advantages of centralized and decentralized systems in a limited sense. Since there is a single control server, the management of the system becomes easier, and the data is also consistent. Moreover, this approach also reaps the benefits of centralized configuration, security and administration: all machines are configured through the central server hosted in the finance department. For inter and intra-departmental communication, direct P2P links are established.

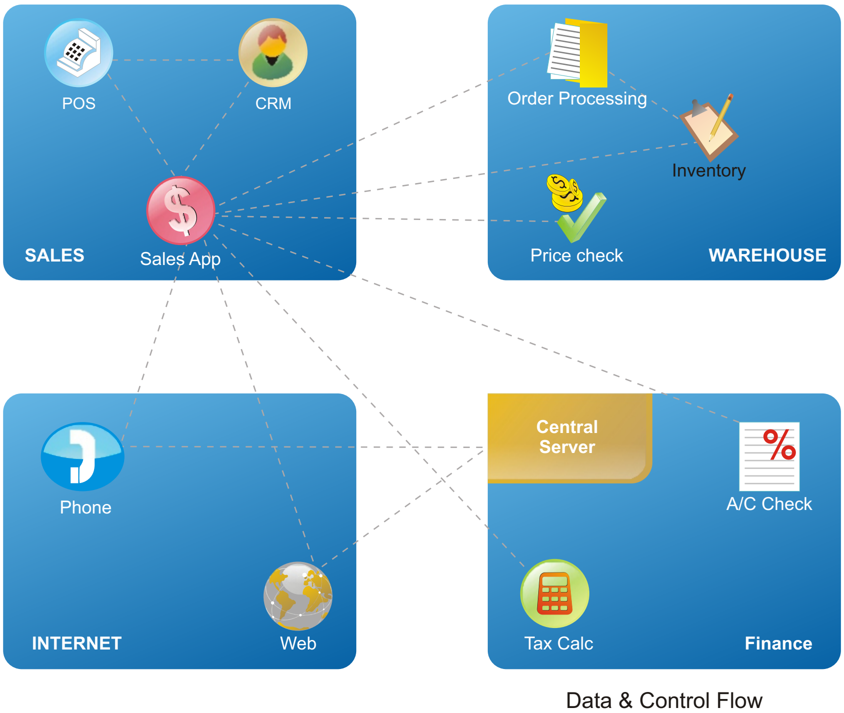

Figure 9: Hybrid peer to peer topology

The hybrid approach does, however, have its own set of disadvantages. Since there is a single control server, there are issues of scalability and presence of a single point of failure. For instance, if the control serer in finance department fails, one cannot add a new machine in any of the departments, and no new business process (which may or may not involve the finance dept) can be initiated. The performance is also decreased as compared to pure P2P systems as the flow of control takes a longer path, resulting in bottlenecks as more clients access the same server.

Super peer topology

A super-peer cluster maps naturally to each business unit. Each department in our application (sales, finance, web and warehouse) can be mapped to a super-peer cluster, as illustrated in the above figure. This architecture allows the composition of complete business processes as a combination of sub processes assigned to a particular super-peer (each which is responsible for all actions within it's particular department).

In this topology, intra-cluster communication takes place in a direct P2P fashion, whilst inter-cluster communication takes place through the super peer. A negotiated contract exists between the two clusters for this purpose. For instance, if the sales department needs to transfer data to the finance department, then the two designated super-peers corresponding to each department communicate based on a predefined contract. There is no central control server to direct this communication. All departments act as autonomous business units, so if the server of finance department crashes, sales and warehouse continue to exchange data, as there is a loose-coupling across different departments.

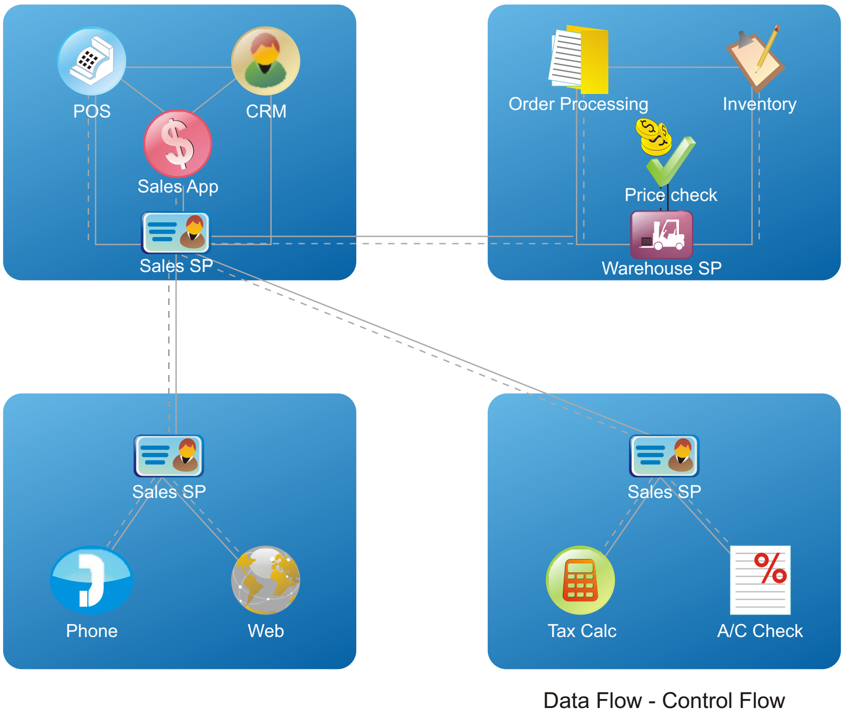

Figure 10: Super peer topology

The super peer architecture truly combines the virtues of centralized and decentralized systems. It alleviates all the problems associated with other topologies. Since data continues to be transferred in a peer-to-peer fashion, the performance is high. Multiple controllers exist, each of which manage their own set of clients, leading to ease of management, configuration and security.

Moreover, since there are very few controllers in the systems, configuration is no longer a problem when compared with the pure P2P approach. The overall system is more secure since multiple controllers (one per department) regulate the flow of data generated by each of the clients. Because we also define the notion of super-peer redundancy, fail over super-peers can be defined, eliminating single points of failure. Overall workload is divided among multiple peers, making the system infinitely scalable. All of these reasons make 2-redundant super-peer architecture the best topology to for the composition

B2B transactions

Super-Peer topology is also ideal for business-to-business transactions. A super peer cluster corresponds to an autonomous business unit and one can open multiple points for interaction across a business unit (B2B interaction) by configuring a small set of super-peers. This leads to increase in performance and scalability. For example in a customer- supplier scenario, any number of separate customers can be added without any scalability issues by adding multiple super-peers at the supplier end, ensuring linear scalability while not impacting ease of configuration or system management.

Summary

Super peer architectures are ideal for distributed business process composition (BPM), Enterprise Application Integration (EAI) and generic distributing computing applications such as compute- intensive scientific problems. Super-Peer platform architecture, supplemented with a coarse-grained component model leads to an extremely reliable, high performance and scalable platform for distributed computing Finally, system designers have to evaluate the requirements for their particular area and pick a topology for the platform that matches their needs.

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A typical business organization has multiple processes that need to be automated, each of which demands a different topology. The super-peer approach is a generic topology which can be specialized to generate all other topologies. If the cluster size is reduced to 1, a super-peer network reduces to a pure peer-to-peer network. If the number of clusters in the network is reduced to 1 the network reduces to a hybrid P2P network and if in addition intra-cluster P2P links are eliminated then the topology reduces to a client/server topology. Thus, implementation of a redundant super-peer topology provides for most efficient, high performance distributed application composition.

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