An overlay network, or virtual network, is a network built on top of a physical network. The nodes of an

overlay network are connected by virtual links that can traverse multiple physical links.Overlay networks

are widely used in many distributed systems such as peer-to-peer systems, content-delivery systems,

and client-server systems; in all these cases the distributed systems communicate through the Internet.

An overlay network can support QoS guarantees for data-streaming applications through improved

routing over the Internet. It can also support routing of messages to destinations not specified by an

IP address; in this case, distributed hash tables can be used to route messages based on their logical

addresses. For example, Akamai is a company that manages an overlay network to provide reliable and

efficient content delivery.

Virtualization is a central concept in cloud computing. We have discussed extensively the virtualization

of processors, and it makes sense to consider also the virtualization of the cloud interconnect.

Indeed, communication is a critical function of a cloud, and overlay networks can be used to support

more efficient resource management. In this section we discuss several possible candidates as virtual

cloud interconnects and algorithms to construct such networks. Such networks are modeled as graphs;

we start our discussion with a few concepts from graph theory.

The topology of a network used to model the interactions in complex biological, social, economic, and

computing systems is described by means of graphs in which vertices represent the entities and the edges

represent their interactions. The number of edges incident upon a vertex is called the degree of the vertex.

Several types of graphs have been investigated, starting with the Erd s-R ny model [53,116,117], in

which the number of vertices is fixed and the edges connecting vertices are created randomly. Thismodel

produces a homogeneous network with an exponential tail, and connectivity follows a Poisson distribution

peaked at the average degree   k and decaying exponentially for k     k. An evolving network, in

which the number of vertices increases linearly and a newly introduced vertex is connected to m existing

vertices according to a preferential attachment rule, is described by Barab si and Albert in [10 – 12,39].

Regular graphs in which a fraction of edges are rewired with a probability p have been proposed

by Watts and Strogatz and are called small-world networks [370]. Networks for which the degree

distribution follows a power law, p(k) ∼ k−γ , are called scale-free networks. The four models are

sometimes referred to as Erd s-R ny (ER), Barab si-Albert (BA),Watts-Strogatz (WS), and Scale-free

(SF) models, respectively [140].

Small-World Networks. Traditionally, the connection topology of a network was assumed to be

either completely regular or completely random. Regular graphs are highly clustered and have large

characteristic path length, whereas random graphs exhibit low clustering and have small characteristic

path length.

The characteristic path length, L, is the number of edges in the shortest path between two vertices

averaged over all pairs of vertices. The clustering coefficient C is defined as follows: If vertex a has

ma neighbors, then a fully connected network of its neighbors could have at most Ea = ma(ma −1)/2

edges. Call Ca the fraction of the Ea edges that actually exist; C is the average of Ca over all vertices.

Clearly, C measures the degree of clusterings of the network.

In 1998, D. Watts and S. H. Strogatz studied the graphs combining the two desirable features, high

clustering and small path length, and introduced the Watts-Strogatz graphs [370]. They proposed the

following procedure to interpolate between regular and random graphs: Starting from a ring lattice with

n vertices and m edges per node, rewire each edge at random with probability 0   p   1; when p = 0

the graph is regular, and when p = 1 the graph is random.

When 0 < p < 1, the structural properties of the graph are quantified by:

1. The characteristic path length, L(p).

2. The clustering coefficient, C(p).

If the condition

n   m   ln (n)   1 (7.1)

is satisfied, then

p → 0 ⇒ Lregular ≈ n/2m   1 and Cregular ≈ 3/4, (7.2)

whereas

p → 1 ⇒ Lrandom ≈ ln (n)/ ln (m) and Crandom ≈ m/n   1. (7.3)

Small-world networks have many vertices with sparse connections but are not in danger of getting

disconnected. Moreover, there is a broad range of the probability p such that L(p) ≈ Lrandom and, at the same time, C(p)   Crandom. The significant drop of L(p) is caused by the introduction of a few

shortcuts that connect vertices that otherwise would be much further apart. For small p, the addition of

a shortcut has a highly nonlinear effect; it affects not only the distance between the pair of vertices it

connects but also the distance between their neighbors. If the shortcut replaces an edge in a clustered

neighborhood, C(p) remains practically unchanged, because it is a linear function of m.