Large-scale systems could be classified as monolithic when all the components work in concert under the

control of a supervising authority and as Systems of Systems (SoS) collections of independent systems

with limited interactions. An analysis of the defining characteristics of an SoS appeared in 1998 [237].

According to this study, a system of systems has five important attributes:

1. The individual components of an SoS, are independent and can be operated alone, disconnected

from the other system components.

2. The components enjoy managerial independence and in fact do operate independently for some

periods of time.

3. The system of systems continually evolves in time as new functions are added while others are

removed.

4. The system is able to perform functions that cannot be performed by any of its components alone;

in other words, it has an emergent behavior.

5. The components exchange only information; thus, they can be geographically distributed over a large

area. As the performance of interconnection networks improves, this geographic spread becomes

less and less noticeable and does not affect the function or the performance of the SoS. This is in

contrast to systems that exchange mass or energy when the distance between components plays a

significant role.

Managerial control distinguishes several classes of systems of systems. A direct system has a central

management that steers the long-term operation of the ensemble of systems; these systems operate

independently most of the time but are subordinated to the common goal. The example of a direct system

given in [237] is an air-defense system in which the individual components can operate independently

but are subject to the requirement to defend the air space.

In the case of collaborative systems such as the Internet, the component systems collaborate voluntarily,

subject to a previously agreed set of rules and objectives. Finally, virtual systems do not have a

central authority to manage their operations. The World Wide Web is an example of a virtual system;

individual sites may or may not follow policies regarding the structure or the contents of the documents,

the naming conventions, or the site navigation rules.