Synchronisation and the Networked Force

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Abstract

We consider the question of how to synchronise a network-enabled coalition force. Classes of situation requiring force-level synchronisation are described, separating the conventional top-down campaign "planned" synchronisation, from the bottom-up mode of "self-synchronisation". This leads us to describe a model of agent behaviour required for self-synchronisation. We follow this up by presenting a discrete event network model to help to quantify the benefit of network warfare synchronisation, and close by considering organisation and communication structures to support self-synchronisation in a large-scale coalition information environment.

1. Introduction

Self-synchronisation has been illustrated [Alberts *et al.*, 1999] as a potential emergent property of a networked force. Self-synchronisation of a collective is facilitated when the actors achieve "network awareness", that is, they share a common perspective of the goals and the environment, underpinned by the communications necessary to allow dynamic alliances to gather and converge.

However, the potential benefits and application of the concept of self-synchronisation to military operations remains largely unarticulated. In operations where internetworking between coalition partners has historically been poor, synchronisation has been planned through clear and deliberate *separation* of activities over the dimensions of time, space, and tasking, largely to avoid fratricide. These seams in the coalition offer vulnerabilities that an adversary may seek to exploit [Carpenter, 1994]. Future joint and coalition operations may be significantly enhanced through a rich coalition information environment, allowing the potential for integration, and new synergies in coalition planning and execution to emerge, sealing up the gaps in these dimensions.

Planned synchronisation of forces is vital in the lead up to an offensive operation where precise timing of effects over a wide area needs to be realised. The potential for self-synchronisation on the other hand, occurs whenever a change in the situation is observed or expected. We examine, categorise and discuss contexts for synchronisation. We also introduce a discrete-event model to establish a basis for quantifying the benefit of network synchronisation. Lastly, we consider a form of undirected communication, which may form a key underpinning for networked situation awareness.

2. Contexts for Synchronisation

The success of joint and coalition warfare in future will rely heavily on the ability of otherwise disparate forces to synergise and synchronise to focus military effects. A 1999 report to the US congress [US Secretary of Defense 1999] on the state of PLA joint and integrated operations describes a familiar story on the maturity of force synchronisation:

"The PLA conducts interservice exercises at the tactical level, but the services are not fully integrated into a cohesive combat force. Disparate elements train simultaneously and in proximity, but do not appear to be controlled at the operational level by a joint commander and staff. Ground and air components exercise together with regularity and are improving their interoperability. Integration of ground and naval forces, however, is rarely exercised, particularly at the operational level, where synchronization and command and control are of greatest importance in the conduct of complex operations. The navy is beginning to conduct more combined operations between ships and naval aircraft. The PLA also is looking into the possibility of instituting a "joint command" structure at the operational or theater level, similar to that of the U.S. military."

Any force is indeed likely to be more effective with operational level synchronisation, however, if such a force was enabled by a network enabling information flows across command levels, reconsideration of the nature of the synchronisation may be necessary.

Conventional synchronisation is planned by an operational commander in an attempt to employ assigned land, air, sea and electronic capabilities to strike the enemy simultaneously throughout the theatre of operations. These strikes are aimed to exploit an enemy's critical vulnerabilities and to allow penetration to the enemy centre of gravity. This planning and scheduling activity is achieved with the cooperation of other national and international efforts devoted to the same objective including for example, diplomatic and economic activities.

Synchronisation of forces is required in the lead up to an offensive operation and whenever a change in the situation is observed or expected. These would include, for example:
a. change of objectives and tasks,
b. regrouping,
c. reallocation of support,
d. change to areas of responsibility of components,
e. change to the time schedule,
f. commitment of reserves,
g. change of subordinate commanders,
h. arrangement of support from higher or adjacent authorities

3. Self-Synchronisation

Change in tasks require a reallocation of resources and is a division of labour problem for which evidence in natural systems [Delgado and Sole, 1998] suggests that self-synchronisation, enabled through minimal communication with neighbours is more efficient than random reassignment of agents to tasks. Of course, reassignment would not be random in a military network, however,

reassignment from a top-down perspective takes valuable time, so that a tactical asset may lose the opportunity to respond to unexpected and perhaps fleeting opportunities to exploit an enemy's weakness. Although this vulnerability may become apparent through shared situation awareness, synchronisation is required to coordinate a rapid and effective response.

Self-synchronisation might be best characterised as the ability of a well-informed force to organise and coordinate complex warfare activities from the bottom up. The most formal definition [Alberts *et al*., 1999] is: *"a mode of interaction between two or more entities … with shared awareness, a rule set, and a value-adding interaction. The combination of a rule set and shared awareness enables the entities to operate in the absence of traditional hierarchical mechanisms for command and control. The rule set describes the desired outcome in various operational situations. Shared awareness provides a mechanism for communicating the ongoing dynamics of the operational situation and triggering the desired value-adding interaction".* Figure 1 accompanies this description:

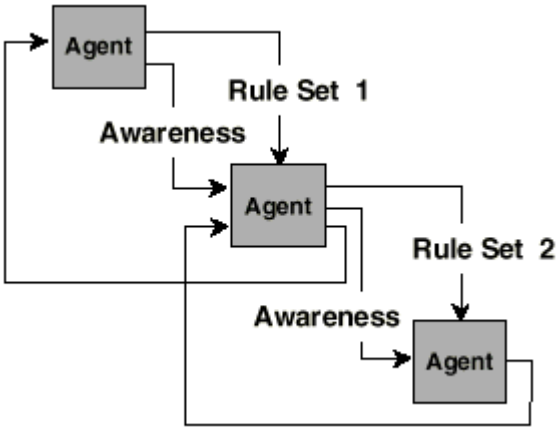

Figure 1. Alberts' Model for Self-synchronisation

Unfortunately, this description and diagram does not penetrate too deeply into an explanation of the behaviour of intelligent self-synchronising agents. To describe what we would consider to be a minimum set of *essential* layers of agent behaviour needed to produce self-synchronisation, we will draw on a model for successful human partnerships [Covey, 1994], illustrated in figure 2.

We assert that the "self" in "self-synchronisation" implies the ability of an agent to arrange timing aspects of its own activities without the influence of other agents. This means that an agent is capable of independence. In order to be truly independent, the agent must firstly be *pro-active,* using situation awareness to best position itself for action with respect to the enemy and as a part of the broader force, rather than reactive in the face of a change in situation. Secondly, the agent must begin its course of action with the command intent and end-state in mind. Thirdly, the agent must be able to prioritise its activities. All of these aspects relate to the behaviour of an individual agent, and are necessary attributes upon which to build its behaviour in a collective environment.

The term “self-synchronisation” is naturally applied not only to an individual agent, but to an arbitrary number of networked agents, and in this sense implies a collective “synchronising” behaviour. This collective behaviour is agent interdependence. Interdependence is built upon the pre-requisite basis of independence. Returning to figure 2, “thinking win-win”, an agent enters into a relationship with another seeking a mutual value-add outcome so both benefit from the exchange – ie. rather than win-lose or lose-win. This involves the sharing of recognition and power, and recognises that the notion of “limited resources” applied to people is flawed. For an agent to seek to first understand others’ perspectives’ before expressing its own, penetrates to the essence of most communication problems – that people do not listen with empathy. When you truly listen to another the relationship is transformed, this involves listening outside of one’s own autobiography. Synergising agents are in a position to self-synchronise to the collective. Synergy produces solutions that are far better than what either agent may have produced originally. Rather than being based on negotiation, which at best achieves a compromise, synergistic communication uses understanding of basic underlying needs and interests to find solutions to satisfy both. The final behaviour not shown in figure 2, is for self-renewal, a process of continuous improvement to refine these behaviours.

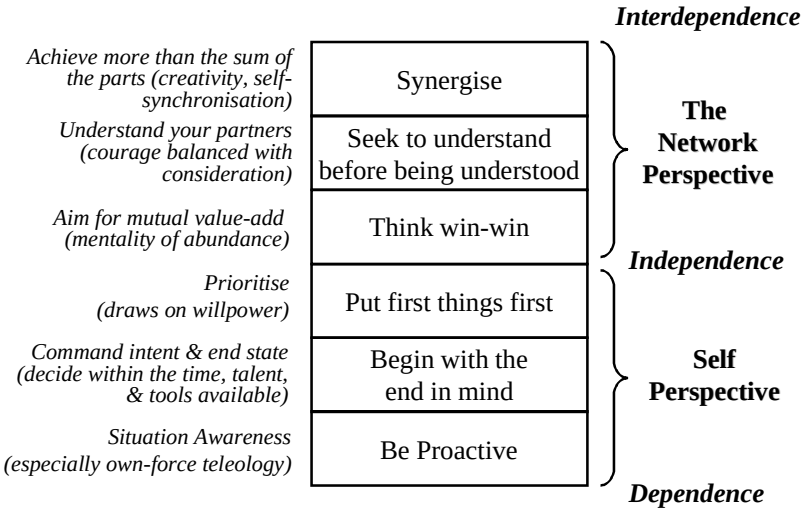

Figure 2. Covey’s model for achieving successful partnerships as a model underpinning self-synchronisation.

A collective of agents behaving in this way organises a flexible and unique set of internal and external linkages for each new operation. Unlike a bureaucracy, with fixed relationships for processing all problems, this networked organisation moulds itself to the operation at hand. It adapts itself not by top-management command, but by interactions with problems, people and resources; and within the broad constraints of the strategy, members *autonomously work out relationships* [Nohira and Eccles, 1992].

Levy [Levy, 1997] describes a synergistic, regulated human group as a “collective intelligence” which is distributed and constantly enhanced, coordinated in real-time, and results in the effective mobilisation of skills. With respect to the temporal dimension of self-synchronisation, Levy comments that time in the networked community spreads itself out, blends with itself and

calmly gathers itself together. The paradox is that to achieve a symphony requires time to make sure that the right agents are involved, to forge bonds, and to agree on actions. However, independent agents have their own periodicities. The information network with intelligent agents is a knowledge space, which although it uses real time technologies, is focussed on its interior rhythms – not to achieve simultaneity within an external time, but to allow adjustment to the environment and to asynchronous situations. Let us now examine a discrete event (asynchronous) model to quantify the benefit of networked synchronisation.

4. A Discrete Event Model for Networked Synchronisation

To examine the benefits of networked synchronisation we extend an existing discrete event system model [Zhang et al 1999], to include synchronisation.

Consider two opposing forces Blue and Red denoted by F_B and F_R, respectively. F_B comprises two command elements, labelled F_B^A and F_B^B respectively, whereas F_R comprises a single command element.

The state set denoted by Ξ, is given by $\Xi = \{U, K, E, S, F\}$[1], where the meanings of the states are:

- U – Unknown: existence of the enemy in the region of operational interest (ROI) is unknown;
- K – Known: the enemy is known to exist in the ROI. The state transition $U \rightarrow K$ may result from intelligence push/pull/assessment, scouting, organic sensing and/or, in the case of synchronisation, network communication;
- E – Engaging: the enemy has been successfully targeted and weapons have been launched. This state effectively combines the processes of localising, targeting and launching against the enemy into a single step;
- S – Succeed: the Blue force has successfully engaged the Red force; and
- F – Fail: the Red force has successfully engaged the Blue force.

Instead of describing the state of the system using a tuple, a dual tuple, $[F_R; F_B^A][F_R; F_B^B]$, is now required. The interpretation of which is illustrated by the following example.

> $[UK][EU]$ means the existence of the Red force, F_R, is unknown to Blue Force command element A, F_B^A, while the existence of F_B^A is known to F_R. At the same time F_R is being engaged by F_B^B, while the existence of F_B^B is unknown to F_R.

We retain the assumptions of unidirectional transition and no simultaneous state transitions occurring to both forces. However, to capture the synchronised aspects of Blue's behaviour, simultaneous Blue transitions are enforced for the synchronised case. This assumption equates to ideal synchronisation between the Blue force command elements, and is represented within those states.

[1] Simplified from Zhang et al's five state model to make the problem manageable.

The following analysis is accomplished using a discrete event model where we define three weighting factors W_s, W_c and W_e which correspond to the transitions $U \rightarrow K$, $K \rightarrow E$, and $E \rightarrow S/F$ respectively. The range of each of these factors is 0 and 1. These factors maybe interpreted as representing the relative effectiveness of the sensing system, the command and control system/process and the weapons performance. These factors are assumed to be the same for both Blue and Red forces, to allow direct comparison of unsynchronised and synchronised models, and normalise the 2:1 blue to red force ratio.

In addition to the weighting factors, transitions between states have a branching factor that describes the relative likelihood of moving from a given state to each of the set of allowed following states. For example for the unsynchronised state [*UK*][*EU*] there are four possible follow-on states [*KK*][*EU*], [*UE*][*EU*], Succeed, and [*UK*][*EK*], all with equal likelihood. Therefore the branching factor for each of these transitions is ¼. Whereas in the synchronised case, state [*KU*][*KE*] has only three follow-on states [*EU*][*EE*], [*KK*][*KE*], and Fail, with branching factors of ½, ¼ and ¼ respectively.

As represented below in Figure 3 the unsynchronised case can be viewed as two independent sub-state 'planes'. For this system there are eighty three possible states, including succeed and fail.

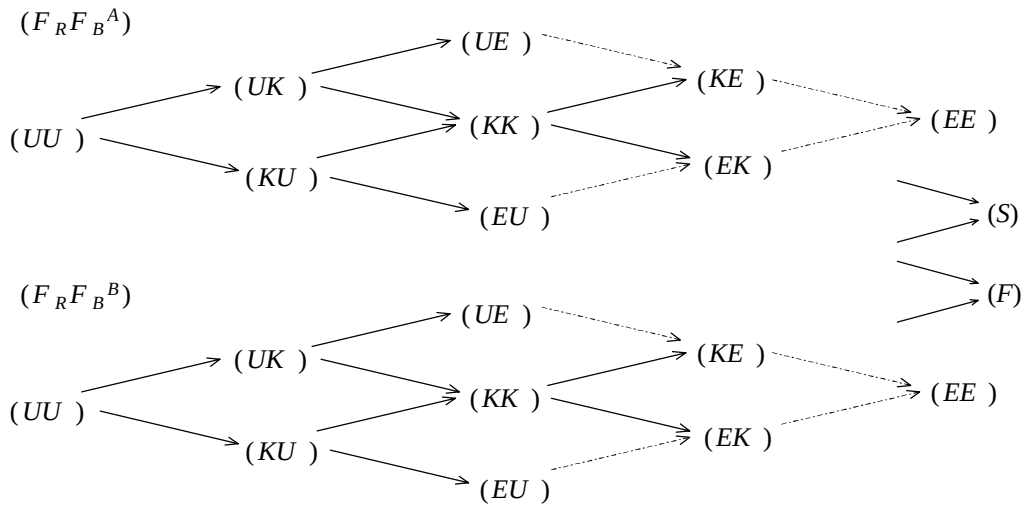

Figure 3. Unsynchronised State Diagram.

Equation 1 describes the probability of successful outcomes as,

$$\text{Succeed} = \frac{\text{WsWcWe}(480\text{Ws}^3 + 1440\text{Ws}^2\text{Wc} + 945\text{Ws}^3\text{Wc}^2 + 315\text{Ws}^3\text{Wc}^3)}{16384} + \frac{(576\text{WsWc} + 1152\text{Ws}^2 + 1152\text{Ws} + 540\text{Ws}^2\text{Wc}^2 + 512 + 1080\text{Ws}^3\text{Wc})}{16384} \quad (1)$$

not surprisingly for the unsynchronised case, equation 1 also describes the failed outcomes. The ratio of success to failure, P(S)/P(F), is unity.

The synchronised case is presented in Figure 4. Networked synchronisation of the Blue force command elements reduces the state space to twenty nine possible states, including succeed and fail. This reduction in states occurs at the expense of Red as equations 2, 3 and 4 show. Effectively bypassing states present in the unsynchronised case, network synchronisation allows the Blue force to transition to engagement more frequently than Red and is the basis for the concept of *getting inside the enemy's OODA loop*. Consequently the Blue force achieves a P(succeed)/P(failure) ratio greater than 1.

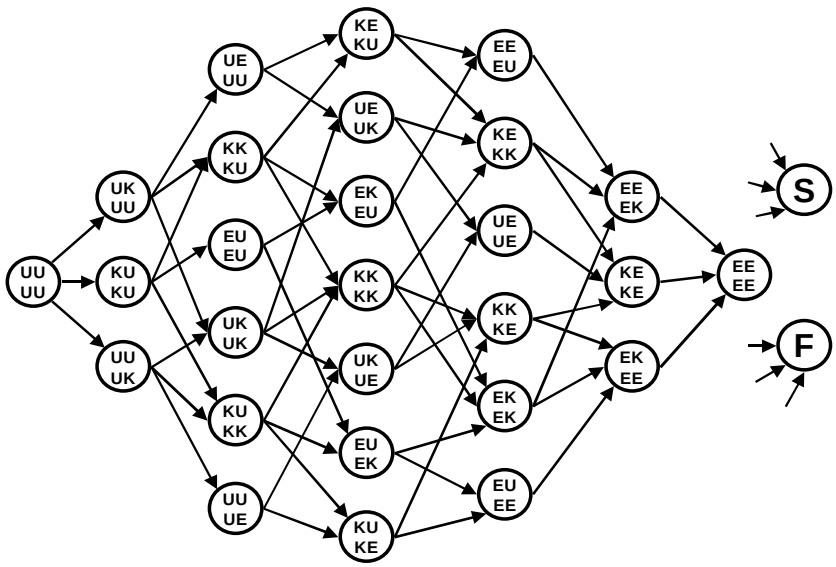

Figure 4. Synchronised State Diagram with representative Synchronisation Transitions.

The successful outcomes for the synchronised case are described by equation 2

$$\text{Prob Succeed} = \frac{\text{WsWcWe}(128+192\text{Ws}+96\text{WsWc}+96\text{Ws}^2+120\text{Ws}^2\text{Wc}+45\text{Ws}^2\text{Wc}^2)}{1024} \quad (2)$$

equation 3 describes the failed outcomes

$$\text{Prob Failed} = \frac{\text{WsWcWe}(32+72\text{Ws}+48\text{Ws}^2+60\text{WsWc}+90\text{Ws}^2\text{Wc}+45\text{Ws}^2\text{Wc}^2)}{1024} \quad (3)$$

resulting in a P(succeed)/P(fail) ratio of

$$\text{Prob S/F} = \frac{(45\text{Ws}^2\text{Wc}^2+(96\text{Ws}+120\text{Ws}^2)\text{Wc}+128+192\text{Ws}+96\text{Ws}^2)}{(45\text{Ws}^2\text{Wc}^2+(60\text{Ws}+90\text{Ws}^2)\text{Wc}+32+72\text{Ws}+48\text{Ws}^2)} \quad (4)$$

The ratio of success to failure is represented in figures 5 and 6 below. Figure 5 presents a surface plot of the success/failure ratio over the range of possible values of Ws and Wc. Because uniform weighting factors were selected for both forces the engagement weighting factor, We, does not influence this ratio.

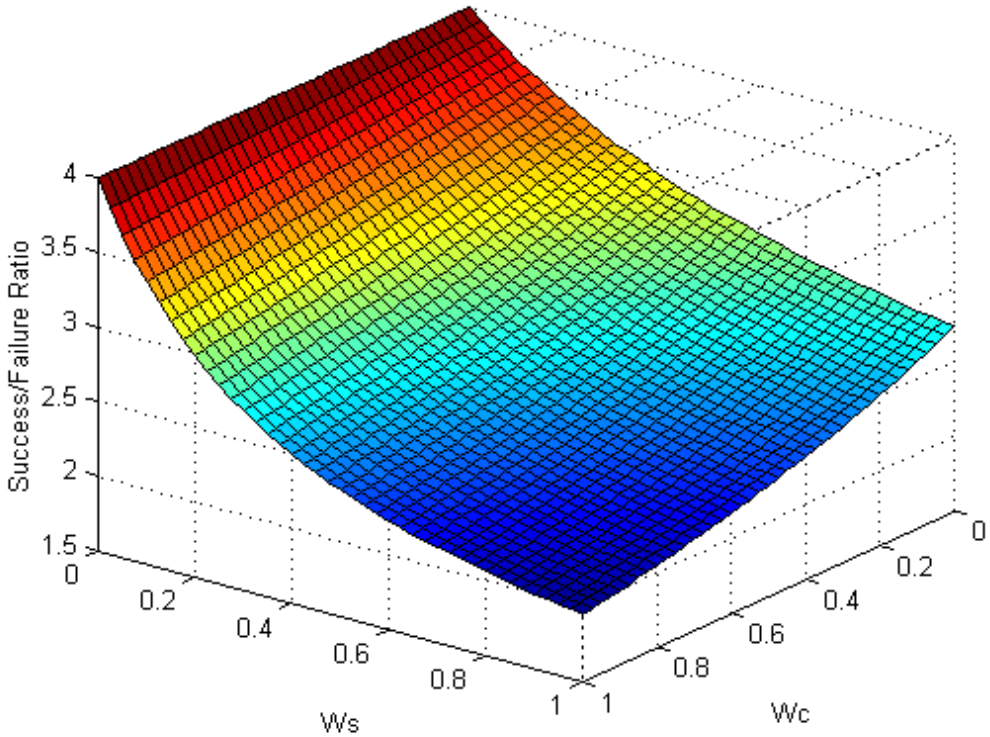

Figure 5. Surface plot of Success/Failure Ratio vs Ws and Wc for the Synchronised Case.

The most obvious conclusion that can be drawn from figure 5 is that regardless of the values of the weighting factors the synchronised force always out performs the unsynchronised one. One can also observe that as the effectiveness of both sensor, and command and control systems, improve in both forces, that the relative advantage of synchronisation decreases. The reduction in this advantage is greater for increasing Ws (sensor effectiveness) than for increasing Wc (command and control effectiveness) as is more clearly seen in figure 6.

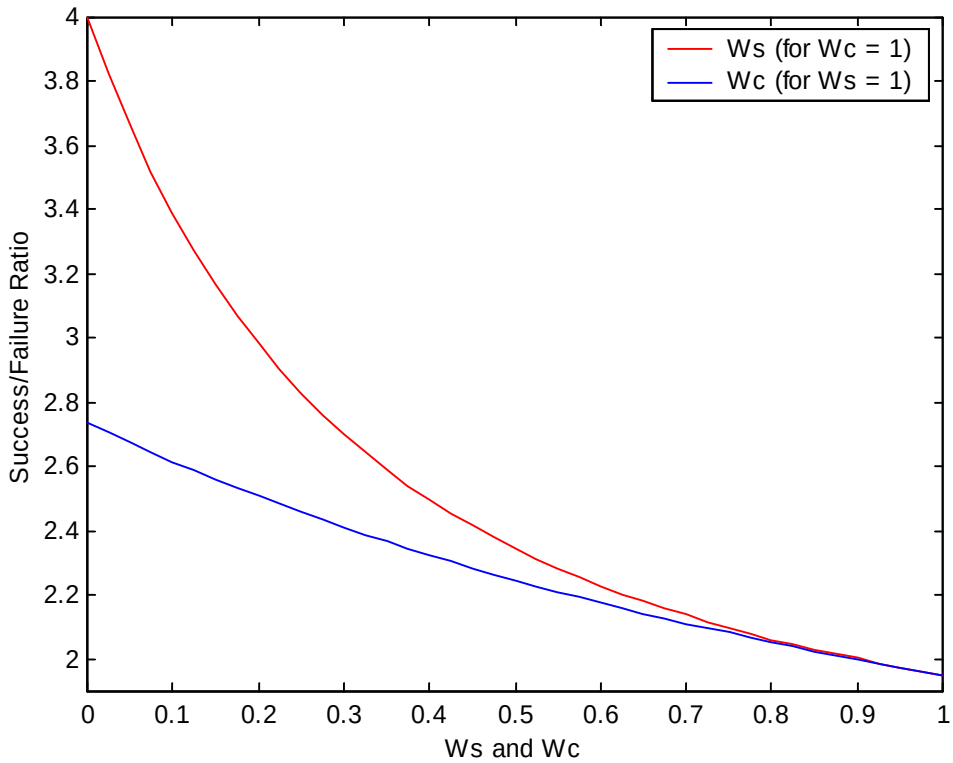

Figure 6. Success/Failure Ratio vs Ws (for Wc = 1) and Wc (for Ws) = 1 for the Synchronised Case.

5. Organisation and Communications for Self-Synchronisation

To facilitate a network-enabled operation, coalition-wide synchronisation of sensor, command, and effects is required. It is not unreasonable to ask why this synchronisation could not be achieved by a simple, centralised, operational command. An illustrative example is the Air Tasking Order (ATO) used with success in the Gulf War to permit coalition-wide synchronisation of air space to reduce fratricide [Carpenter, 1994]. This centralised process worked for the air environment, but there are a number of reasons why the ATO approach is unlikely to facilitate self-synchronisation:

1. It is largely top-down, and new target opportunities often arise within the ATO schedule period which cannot be serviced without significant whole-of-force reprioritisation and rescheduling;
2. although aimed to shrink considerably through ongoing US research programs, the ATO schedule planning-to-dissemination period is finite, and criticality is shifted to communication of the schedule which must be acknowledged by *all* participating force elements before execution;
3. a schedule of air space usage does not reveal the full teleology behind it to the tactical-level participants, so that local constraints are not accounted for, and unforseen efficiencies cannot be exploited;

4. in theory, fratricide is a tactical issue[2] not for the operational level of war and therefore should be controlled at the tactical level.

So, to allow coalition-wide synchronisation of sensor, information, and effects we argue that first 'global' visibility of the teleology of those C4ISR assets be available. That is, the whole of the force must be aware of the what, who, how, when, where and why of the proposed use of available C4ISR and effects assets – such a schedule would include what asset is proposed to be used, who is requesting access to it, who has authority for its use, how it is to be used, when it is to be employed, where it is to be employed / moved to, and why that asset was chosen. This information must be generated and shared by the force. C4ISR-effects visibility means shared information on ISR assets – from organic radars to strategic reconnaissance platforms; C4 assets – including satellite capacity usage, network connectivity status and security; and "effects" assets – including use of long-range precision weapons, EW and IO.

In this model, the CJTF HQ generates only that part of the schedule of asset usage for critical operationally-synchronised strike operations, and is *responsible* for ensuring that strategic C4ISR and effects assets are appropriately employed, protected and negotiated for service-level users to task.

To make best use of C4ISR assets, a communication system that facilitates an information ecology must be constructed. At any time, an agent may be a producer or consumer of information, leaving the significant challenge of routing information to other agents who require it. If an agent has information to share (eg a ship's combat system registers after an engagement that five less missiles are available in its rack), it may be difficult to decide who (other than the enemy!) would benefit from knowledge of the event, and therefore who to send the information to. In this example, the information would clearly be of interest to other ship agents, however, it may not be clear to the producing agent that this information may be used immediately by shore-based logistics to plan resupply (which may be provided through a coalition partner).

The publish / subscribe model is a common and simple protocol used in distributed systems (particularly middleware) as illustrated in figure 3. However, due to the free-form nature of information, the use of subscription channels or categories (as is common in existing command support systems eg. Lotus Notes) does not scale – the number of information classes soon becoming too large to manage. To deal with this, the Elvin system [Arnold *et al*, 2000] searches the *content* of published information to match it to a set of rules in the subscription specification, thereby allowing only specific information relevant to the consumer to pass, who is notified of the availability of that information.

Figure 5. Undirected communications model.

[2] Elicited from discussion with VADM Arthur Cebrowski. Note however, that without a self-synchronisation framework, there is no clear way to control fratricide at the tactical level.

The simplicity of this model belies the sophistication of network relationships that may emerge as a direct result of its employment.

6. Conclusions

We have considered the nature of synchronisation and particularly self-synchronisation in the context of a network-enabled, coalition force. We believe that an improved model of agent behaviour (both human and intelligent computer-based entities) in a networked environment is necessary to progress development of these concepts beyond situation awareness. The principles of this model may be incorporated into doctrinal procedures. New mechanisms for establishing agent networks such as the publish / subscribe model described here are vital to allow dynamic alliances to emerge and realise the potential for self-synchronisation.

7. References

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