

# **Spectrum Collaboration Challenge**

## **SC2 Championship Event Scoring Procedures**

October 20, 2019

*FINAL*



---

**Defense Advanced Research Projects Agency**  
675 North Randolph Street  
Arlington, VA 22203



## Revision Summary

<b>Revision</b>	<b>Date</b>	<b>Description</b>
1	February 1, 2019	(DRAFT) Initial Release for SCE
2	March 29, 2019	(DRAFT) Corrections, defines Tournament Structure
3	April 15, 2019	(DRAFT) Corrected the required percentage for file transfers. Clarified definition of Steady State Period.
4	August 1, 2019	Clarified Round-Robin and Elimination Match tiebreaker rules
5	August 13, 2019	Clarified Round-Robin tiebreaker rule
6	September 12, 2019	Added Defective Radio rule and implementation mechanism
7	October 20, 2019	Final version – no changes from revision 6

# SC2 CHAMPIONSHIP EVENT, FINAL SCORING PROCEDURES

## 1 Overview

This document defines scoring procedures for the SC2 Championship Event (SCE). These procedures apply to all participants in SC2. Further refinements and clarifications to this document will be released as needed. Prior to the SC2 Championship Event, a final scoring document will be released. That document will be clearly marked FINAL, all others will be marked DRAFT. The Final Scoring Procedures document will carry the full authority of the rules in the SC2 Rules document as outlined in Section 8 of the SC2 Rules.

The Scoring procedures laid out in this and any future version of this document are subject to change at DARPA's sole discretion as outlined in the SC2 Rules Document Section 7.1.

## 2 Tournament Scoring

### 2.1 Tournament structure

SCE is composed of a series of elimination rounds and a final round. The number of teams participating decreases through the elimination rounds until the final round, which determines the prize winners of the SCE. Scores are zeroed out at the beginning of each round; there is no carryover of points between rounds.

SCE Round	Type	# Teams entering Round	Round Result
1	Elimination	10	1 team eliminated
2	Elimination	9	1 team eliminated
3	Elimination	8	1 team eliminated
4	Elimination	7	1 team eliminated
5	Elimination	6	1 team eliminated
6	Final	5	Top 3 teams prize eligible

### 2.2 Elimination Rounds

Each Elimination round consists of a Round-Robin and a Knockout.

#### 2.2.1 Elimination Rounds: Round-Robin

The Round-Robin is a collection of matches played in one or more scenarios. A team's score in the Round-Robin is computed from its scores in the matches of that Round-Robin.

$$\text{Round-Robin Score} = \sum_i \text{Match Score in match } i$$

The Round-Robin Ranking orders the teams by Round-Robin Scores, with the highest score earning the highest rank.

The two teams with the lowest Round-Robin Rankings compete in the Knockout. The other teams advance directly to the next round.

## SC2 CHAMPIONSHIP EVENT, FINAL SCORING PROCEDURES

Tiebreaker #1: In case of a tie Round-Robin scores, the Round-Robin Rankings will be determined by the total time above the Ensemble Threshold (see Section 3.1). The teams with the lowest Above Threshold Time will compete in the Knockout.

Tiebreaker #2: In case of a tie in Above Threshold time (Tiebreaker #1), the Round-Robin Rankings will be determined by the rankings of the previous round. If the previous round is also tied, then rankings will be established by previous rounds in turn; if a tie occurs in the first Elimination Round, then the Play-In Round rankings will be used. The Play-In Round is the set of matches that determines the 10 finalists that will be invited to the SC2 Championship Event.

### 2.2.2 Elimination Rounds: Knockout

The Knockout is a single 5-team match. The 3 highest ranked teams in the Round-Robin ranking participate in the Knockout match as placeholders only, and are not scored.

A Knockout match concludes when one of the two competing teams reaches the Finish Line score (see below), or time expires. The Knockout Ranking is determined by comparing Knockout Match Scores of the two competing teams. The team at the bottom of the Knockout Ranking is eliminated from the tournament.

Tiebreaker #1 : In case of a tie in Match Points, the Knockout Ranking is determined by comparing the total time above the Ensemble Threshold (see Section 3.1) by each competing team in the Knockout Match. The team with the least Above Threshold Time is eliminated from the tournament.

Tiebreaker #2 : In case of a tie in Above Threshold time (Tiebreaker #1), the Knockout Ranking is determined by comparing each teams' Round-Robin Ranking in the current round.

## 2.3 Final Round

The Final Round consists of one or more 5-team matches. Each match gives teams the opportunity to earn Prize Points based on their rank in that match, according to the table below.

Rank of team's Match Score in that match	Prize Points earned
1	10 points
2	8 points
3	7 points
4	6 points
5	5 points

In case of a Match Score tie among two or more teams, each earns the same Prize Points as the top-ranked tied team. However, if all five teams tie, no Prize Points are earned for that match. If the Finish Line (see below) is not achieved by any team before time expires, no Prize Points are awarded to any team.

## SC2 CHAMPIONSHIP EVENT, FINAL SCORING PROCEDURES

The Final Round ranking is determined by Total Prize Points.

$$\text{Total Prize Points} = \sum_i \text{Prize Points earned in match } i$$

Tiebreaker 1: In case of a tie, the Final Round ranking between the tied teams is determined by comparing Final Round Scores.

$$\text{Final Round Score} = \sum_i \text{Match Score in match } i$$

Tiebreaker 2: In case of a further tie, the Final Round ranking between the tied teams is determined by comparing each team's total Round-Robin Score from all elimination rounds.

### 2.4 Tournament Ranking

The final tournament ranking is determined as follows.

Tournament Rank	Team
1 to 5	Ordered according to the Final Round ranking
6 to 10	In reverse order of elimination from the tournament

The top 3 teams in the final tournament ranking will be eligible for prize awards in accordance with the SC2 Rules.

## 3 Match Score

Each SCE match is divided into *stages*. During a stage, each network is given a number of *individual mandates (IM)*. An IM specifies the required wireless communications performance parameters for a particular IP traffic flow, and an associated number of points. A team can earn the points specified for that flow in each *measurement period* of time that it carries the flow, after an initial *steady state period*. A team's match score is the sum of the points earned in all measurement periods of the match that are not declared to be *unscored measurement periods*.

There is a pre-established threshold at which the ensemble must perform. The threshold for each team is a fraction of the maximum possible points that team could earn in each measurement period. When the lowest performing team is below its threshold, each team earns only the minimum of the points scored by any team (the *ensemble score*). When the lowest performing team is above the threshold, each team has the opportunity to earn bonus points based on its individual performance, irrespective of the performance of other teams.

In Knockouts and Final Round, the scoring in each Match stops after the Measurement Period in which one or more of the participating networks' Match Score first meets or exceeds a Finish Line score specified by the scenario. All Measurement Periods after that Measurement Period will be declared to be unscored measurement periods.

In addition to IMs, scenarios have *gates*. A gate is a required behavior not associated with an individual IP traffic flow. A network cannot meet the required parameters of any of its IMs when a gate is being

violated. Thus, no network earns points in measurement periods during which there is a gate violation, or during the following steady state period for each of its flows.

The following sections detail the above outlined scoring procedure.

### 3.1 Match Score Formulas

Measurement Period (MP): An MP is an interval of time in a stage over which performance parameters are assessed. The length of the measurement period (MP) for SCE is 1 second. All times  $t$  referred to in the below are discretized to  $MP$ .

Scored MP: A scored MP is one in which teams may earn points. In unscored measurement periods, no team's score is modified irrespective of gates met or IMs achieved.

Gates: A gate is a required behavior not associated with an IP traffic flow. A gate is met if the network or ensemble complies with the required behavior.

Performance Thresholds (PT): A PT is a required behavior of an IP traffic flow, such as required throughput or latency. The PT is deemed to be met in a given MP if the associated parameter meets or exceeds the specified threshold in that MP.

During a given MP, if no IP packets are offered, or if the parameters of a PT do not require the delivery of IP packets, the following conditions hold:

- The PT is deemed to be met if it was met in the previous MP.
- The PT is deemed to be not met if it was not met in the previous MP.

Individual Mandates (IM): An IM  $i$  provided to a network specifies the following: one or more PTs for an IP traffic flow, an associated point score  $P_i$ , and a steady state period  $SSP_i$ . An IM is deemed to be achieved at time  $t$  if the following conditions hold.

- The specified PTs have been continuously met for  $SSP_i$  MPs.
- No gate has been violated in  $SSP_i$  MPs.

$SSP_i$  may be any positive integer. The current MP is included in the count. For example, if  $SSP_i = 2$ , the IM is deemed to be achieved if the PT was met in the previous MP and in the current MP, and no gate was violated in the previous MP or the current MP.

Measurement Period Score (MPS): The MPS is the total points associated with the IMs achieved in one MP by a single network.

$$MPS_t = \sum_{IMs\ i} S_{i,t}$$

where

$$S_{i,t} = \begin{cases} P_i, & \text{if IM } i \text{ achieved at time } t \\ 0, & \text{if IM } i \text{ not achieved at time } t \end{cases}$$

Relative Measurement Period Score (RMPS): The RMPS reflects the percentage of traffic carried by a network in a single MP.

$$RMPS_t = \frac{MPS_t}{\sum_i P_i}$$

Ensemble Threshold (ET): The scenario specifies an ET for each stage. The ET is provided to all networks.

Points Earned (PE): In the MP at time  $t$ , network  $N$  earns  $PE_{N,t}$  points.

$$PE_{N,t} = \begin{cases} MPS_{k,t} & \text{if } RMPS_{m,t} < ET \\ MPS_{N,t} & \text{if } RMPS_{m,t} \geq ET \end{cases}$$

Where  $m$  is the lowest performing network of the ensemble measured as a percentage, and  $k$  is the lowest performing network of the ensemble measured by points scored:

$$m = \underset{\text{networks } j}{\operatorname{argmin}} RMPS_{j,t}$$

$$k = \underset{\text{networks } j}{\operatorname{argmin}} MPS_{j,t}$$

Finish Line (FL): The scenario optionally specifies a Finish Line score for the match. The FL is not provided to networks and they are not informed whether one is specified.

Match Score: The Match Score for network  $N$  is:

$$\text{Match Score}_N = \begin{cases} TPE_N & \text{if finish line unspecified or } \max_{\text{networks } j} TPE_j \geq FL \\ 0 & \text{if finish line specified and } \max_{\text{networks } j} TPE_j < FL \end{cases}$$

where

$$TPE_N = \sum_{\text{Scored MPs } t} PE_{N,t}$$

### 3.2 Individual Mandates

An *IP traffic flow* is a unique instance of IP traffic of a single application layer type to be delivered between source and destination IP addresses that are both in the team's network.

An Individual Mandate (IM) has the following components:

- 1) A Flow Unique Identifier (flow UID) that identifies an instance of a specific traffic type, a source IP address, and a destination IP address.
- 2) Performance Thresholds (PT) for the IP traffic flow.
- 3) A Steady State Period (SSP)
- 3) A point score (P) that can be earned in each measurement period

The PTs and their associated interpretation are given in Table 1. The below performance thresholds are computed by the scoring subsystem for each Measurement Period (MP) during the match.

**Table 1 – Performance Thresholds and associated scoring interpretation.**

<b>Performance Threshold</b>	<b>Description</b>
<i>max_latency_s</i>	The maximum allowed latency (in seconds) for any IP packet in the flow during the measurement period.
<i>min_throughput_bps</i>	The minimum allowed throughput for the flow during the measurement period.
<i>file_transfer_deadline_s</i>	The maximum allowed latency (in seconds) for <del>100%</del> 90% of the packets of a file transfer to occur.

Throughput is measured as bits per second of IP traffic delivered to the traffic generator sink at the destination node.

Packet latency is measured from when the traffic generator source provides a packet to the source node to when the traffic generator sink receives it from the destination node. A packet which is not delivered in less than *max\_latency\_s* is considered dropped, decreasing the measured throughput, even if it is eventually delivered.

File transfer latency is measured from when the traffic generator source provides a packet to the source node to when the traffic generator sink receives it from the destination node. Latency is measured on a per packet basis. 90% of packets offered in a MP must be delivered in order to meet the PT. A packet which is not delivered in less than *file\_transfer\_deadline\_s* is considered dropped.

The flow types and their associated default point scores are given in Table 2.

**Table 2 – Flow Types and Default Point Values**

<b>Flow Type</b>	<b>Points</b>
BFT	1
FTP	3
Imagery	2
SMS	1
UAV Control (C2)	4
Video (continuous)	10
Voice	4
Web page download	9
Web page request	1

*Note:* Point values may vary from those above to emphasize priority of specific classes of traffic or specific flows.

### 3.3 Gate: Incumbent Protection

An *Incumbent* is a radio spectrum user that must be afforded protection in the spectrum. In scenarios with Incumbents, protecting the Incumbent is a gate for the mandated outcomes.

An *informing Incumbent* is one that provides feedback via the collaboration network to inform other radio networks if its threshold has been violated. Informing incumbents may have a threshold set as a function of acceptable interference power, or have a threshold based on acceptable degradation of nominal throughput.

In either case, an informing incumbent will advertise both its current threshold (interference power in dBFS, or minimum throughput in bps) as well as its current measurement against the threshold (interference power in dBFS, or achieved throughput). These reports will be sent every *Reporting Period*. A *Violation Period* is comprised of a number of successive Reporting Periods. The current threshold will not change during a Violation Period. If the average of the reported measured values over the Violation Period exceeds the current interference power threshold, or is below the minimum throughput threshold (whichever is applicable), the Incumbent is deemed to have experienced interference during that entire Violation Period. This is referred to as an *Interfering Violation Period*.

The *incumbent protection gate (IPG)* is deemed to be met during an MP, if no Violation Period in or overlapping that MP is an Interfering Violation Period.

### 3.4 Gate: Transmission Only in Allowed Bandwidth

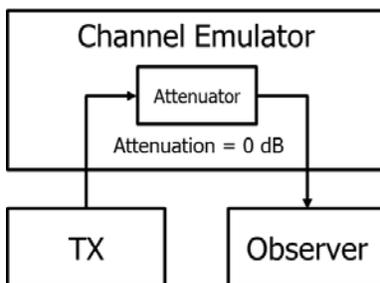
RF transmissions are only permitted within the allowed bandwidth of each scenario. Respecting the allowed bandwidth limit is an additional gate for the mandated outcomes.

A transmission outside the allowed bandwidth is determined according to the following equation, with variables as defined in Table 2:

$$PSD(f_{disallowed}) > \Gamma$$

**Table 2: Variables for determining transmission outside of allowed bandwidth**

Variable	Description	Value in PE2
$PSD(f_{disallowed})$	The power spectral density of any transmitting node at frequency $f_{disallowed}$ as observed by the observer node with 0 dB of digital attenuation (see Figure 1)	<i>variable</i>
$\Gamma$	Transmission energy threshold referenced to full scale (dBFs). “Full scale” refers to the maximum signal that can be represented by the observer A/D converter.	-141 dBFs/Hz



**Figure 1 – Configuration of observer node**

## SC2 CHAMPIONSHIP EVENT, FINAL SCORING PROCEDURES

Multiple power spectral density observations will be taken of the transmissions of each node within a measurement period by an observer. Each PSD observation will average the power received over a time window. The length of the time windows is not specified in advance and may change during the course of a match.

The receiver gain of the observer node will be set according to Table 3 below. The gain of the closest center frequency to that of the scenario is used.

**Table 3: Observe Node Receiver Gains**

Center Frequency	Observer Receive Gain
1.0 GHz	7 dB
2.4 GHz	8 dB
5.8 GHz	15 dB

The *transmission bandwidth gate (TBG)* is deemed to be met during an MP if no transmissions beyond the allowed frequency bandwidth are detected within that MP.

### 4 Feedback to networks

A team's network does not receive real-time feedback on scoring. Specifically, the system does not inform the network whether any IM has yet been achieved in the current stage, or whether applicable gates have been met.

### 5 Additional Rules

#### 5.1 Fair play rule

A network is considered to violate fair play if, in the opinion of DARPA, it shows a pattern of intentionally reducing its score from above to below the Ensemble Threshold in order to gain an advantage. A team whose network violates fair play may be disqualified from the tournament. If disqualified, a team does not receive a final tournament ranking and is ineligible for a prize.

If disqualified in an elimination round, the network is eliminated after the round robin. No knockout match is held. If disqualified in a match of the final round, it participates in no further matches.

#### 5.2 Defective network rule

A network is considered to exhibit defective behavior if, in the opinion of DARPA, it fails to accomplish a de minimus number of individual mandates for extended periods of time, when prior performance indicates it should perform better given the conditions of that scenario.

If a network exhibits defective behavior in an elimination round, the team is eliminated after the round robin. No knockout match is held. If a network exhibits defective behavior in a match of the final round, it earns no Prize Points for that match but continues to participate in further matches.

### 5.3 Final round placeholder

If DARPA judges that one of the rules of this section applies in a match of the final round, that match is re-executed without participation by the subject network. A different network from among those previously eliminated is selected by DARPA. That network participates in the re-execution of the match as a placeholder.

If a team is disqualified during the final round, a placeholder replaces it for all remaining matches.

Placeholder networks are not scored, are not eligible for a prize, and their final tournament ranking does not change.